Progress Report Number 5
Project 2.1
Metabolism and Dosimetry of Plutonium Industrial Compounds

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Executive *Summary*

The long-term collaborative research Project between the Dosimetry Registry of the Mayak Industrial Association (DRMIA), operated by Branch N1 of the SRC Institute of Biophysics, and the U.S. Transuranium and Uranium Registries (USTUR), operated by Washington State University, under the sponsorship of the U. S. Department of Energy (DOE) continues into its second year.

The main purpose of the Project is to combine materials accumulated by both Registries, create a joint database, and perform a mutual analysis of this unique information regarding metabolism and dosimetry of transuranium nuclides, specifically plutonium and americium, in the human body.

The primary focus of the first year of this collaborative research program (April 1997 - April 1998) was to conduct a laborious, but very important task which was an intercomparison of radiochemical analytical methods and instrumentation currently in use by both Registries for determination of plutonium and americium in autopsy samples (Task A). The intercomparison was a necessary prelude to the combination and mutual use of analytical results which were obtained by different methods as well as for the quality assurance of previously accumulated data. This intercomparison of radiochemical and instrumental methods for Pu and Am determination included the radiochemical analysis of 20 samples prepared by each laboratory. There were no overall statistically significant differences between the results of plutonium and americium determination in soft tissues or in bones samples. The results of the intercomparison allow the conclusion that the data accumulated by the both Registries are valid, correct, and can be used in the joint investigations of actinide metabolism.

The last stage of the laboratory intercomparison was to have included an analysis of the isotopic composition of Standard Reference Materials (SRM), certified by the U. S. National Institute of Standards and Technology (NIST). However, this stage has been delayed because of changes in the import regulations of Russia. To obtain state licenses for the import of the SRM and the plutonium, thorium, and uranium isotopes which were purchased in April 1998, additional funds will be needed by the DRMIA. This problem was discussed with representatives from the DOE during their visit to Ozersk in September, 1998 and they are currently exploring possible solutions.

During the first year of this project, a database to be jointly used by both Registries was formatted and Russian and American investigators began entering their respective data. At present time, the joint database is in use for collaborative research on actinide metabolism (Tasks F, G, and H).

Another high-priority task included coordination of radiochemical analytical procedures for plutonium and americium separation and detection in low activity biosamples (Task D). The DRMIA has significantly modernized their radiochemical methods for plutonium and americium analysis in biosamples by application reagents currently in use by the USTUR, such as Bio-rad resins and the DDCP extractant. To further increase the sensitivity and efficiency of the methods, the DRMIA has acquired a 16 chamber alpha-spectrometry system (EG&G Ortec OCTETE), purchased in June, 1998. However, the calibration of the alpha-spectrometer was delayed because of the above mentioned changes in regulations of State Custom Committee (RF) regarding the import of radioactive materials. Calibration of the alpha-spectrometer is expected to be delayed until the end of 1998.

During the current reporting period, studies of the physico-chemical properties of alpha active workplace aerosols (Task E) have continued. The method for determination of the transportability coefficient are presented, current results were analyzed and results of the former research were summarized in this report to establish the value of this coefficient for studying metabolism of inhaled plutonium. The data on transportability were used for an investigation of plutonium distribution between the lungs and systems of workers and they indicated a definite inverse correlation between the lung:system plutonium concentration ratios and the transportability coefficient (solubility), as measured by the DRMIA, of aerosols collected in actual workplaces of the workers.

Three tasks involving biokinetic modeling were initiated during this reporting period. Data relating plutonium concentrations in the skeleton and liver suggest that disease conditions involving the liver have an effect on the exchange of plutonium between the two organs when compared to liver and skeletal concentrations in healthy individuals. There was a slight increase in skeletal concentration relative to that of liver in those individuals with severely diseased livers, which included cirrhosis, primary and metastatic cancers in the liver and marked fatty degeneration of the liver.

The modernization of the whole-body counter (WBC), currently in use by FIB-1, was initiated during this year by moving an excess WBC from the Rocky Flats site to Ozersk (Task I). The WBC was disassembled, packed and shipped to Russia on 1 September 1998. The construction of a WBC room at FIB-1 was finished by September 15, 1998. It was decided to construct a temporary roof over the room until after the WBC installation. For the construction of a permanent, roof some additional funds will be required. Estimates indicated that the approximate price of the WBC transportation from destination to place of assembling, mounting and installation will be $25,000. The assembling and installation of the complex equipment will be performed by D.Hickman, LLNL, jointly with Russian specialists in the DRMIA laboratory, Ozersk in October-November 1998.

Four articles were published during this reporting period (Task J):

1. Filipy, R.E.; Khokhryakov, V.F.; Suslova, K.G.; Romanov, S.A.; Stuit, D.B.; Aladova, E.E.; Kathren, R.L. Analysis for Actinides in Tissue Samples from Plutonium Workers of Two Countries. Journal of Radioanalytical and Nuclear Chemistry 234(1-2): 171-174; 1998.

2. Khokhryakov, V.F.; Suslova, K.G.; Tsevelyova I.A.; Aladova, E.E.; Filipy, R.E. Classification of Alpha-active Workplace Aerosols Based on the Coefficient of Transportability, Measured by the Dialysis Method. Jounal of Radioanalytical and Nuclear Chemistry 234(1-2): 209-212; 1998.

3. Khokhryakov, V.F.; Kudryavtseva T.I.; Chernikov V.I.; Suslova, K.G.; Orlova, I.A.; Filipy, R.E. A Scintillation Method for Determination of Actinide-Alpha Activities in Samples. Journal of Radioanalytical and Nuclear Chemistry 234(1-2):293-295; 1998.

4. Khokhryakov V.F.; Suslova K.G.; Tseleva I.A.; Aladova Ye.Ye. Objective Method for Classifying Alpha-Active Aerosols for Dosimetry of Internal Irradiation. Medical Radiobiology and Radiation Security 4:41-45;1998.

Progress

The following tasks were planned for initiation during this reporting period of Project 2.1 (April-September 1998):

F. Analysis of the combined DRMIA-USTUR database to establish the lung clearance coefficients for plutonium and americium compounds to systemic circulation based on respiratory tract:systemic concentration ratios from both Registries.

G. Evaluation of the combined DRMIA-USTUR database to establish relationships between the actinide concentrations in systemic organs, and also between their concentrations and systemic concentrations in healthy individuals and in those with diseases (specifically liver diseases) that may have affected actinide metabolism.

H. Analysis of combined data from both Registries to establish relationships between the actinide contents of body organs and the whole body at autopsy and those predicted by long-term urinary actinide excretion rates in modern ICRP models for healthy individuals and for those with liver diseases.

Proposal of these tasks was based on preliminary investigations by the DRMIA regarding the dependence of plutonium behavior on physico-chemical properties of inhaled aerosols as well as on the influence of liver pathology on the actinide metabolism in the body (Khokhryakov et al. 1994, Suslova et al. 1994). Specifically, Task G was proposed as a follow-up to a report by Filipy et al. (1994; 1996) in which actinide concentration relationships were used to predict retention half-times in a number of soft tissues, based on a selected set of data.

The progress reported in this document for Tasks F, G, and H is very preliminary as they are quite broad in scope and the work was just begun. Only minimal statistical analyses were performed on results of those tasks for this report and much data verification and, possibly, reanalysis remains to be performed.

Task A. Intercomparison of radiochemical analytical methods used by the two Registries for determination of actinides in autopsy samples.

This task was originally planned to be accomplished in three steps:

1. Intercomparison of instrumental methods and equipment for plutonium and americium measurements,

2. Intercomparison of radiochemical separation as well as measurement methods, and,

3. Analyses of Standard Reference Materials (SRM) prepared by the U. S. National Institute of Standards and Technology (NIST).

The first two of these steps have been completed and the data were presented in the progress report for the period 1 October 1997 - 10 March 1998. During the present reporting period the data were subjected to a rigorous statistical analysis. The overall conclusion of the laboratory intercomparison was that, despite the major differences in radiochemical analytical methods and dectection instrumentation used by the two Registries, the analytical results for samples analyzed by the two laboratories were not statistically significantly different and the data were determined to be compatible for joint analysis.

Statistical methods

Both USTUR and DRMIA provided results of analyses of samples exchanged for comparison of radiochemical extraction methods. Analysis of variance was used to test for significant differences in means for radiochemical analyses by the two laboratories as well as differences due to extraction by radiometry or spectrometry. A randomized complete block design was assumed which provides a statistical analysis equivalent to a paired t-test when comparing two mean values but allows simultaneous comparison of

three means (e.g., USTUR spectrometry, DRMIA radiometry, DRMIA spectrometry). Both unweighted and weighted analyses of variance were applied because estimated standard deviations were unequal among samples. Inverse variance weighting was used to account for nonhomogeneous sample variation. Normality was assumed because the data represent disintegrations per minute averaged over long periods of time. Average values tend to be normally distributed even when the original data are not normally distributed.

Radiochemical analyses of exchanged samples were further compared visually with scatter plots of data from one laboratory plotted against data from the other laboratory or data from one method of extraction plotted versus data from another method of extraction. A 45° reference line was plotted to aid in identifying systematic differences between extraction results.

A statistical power analysis was also conducted to assess the adequacy of the number of samples in detecting meaningful differences between laboratory radiochemical extraction results.

Statistical Results

Interlaboratory comparison of data from five DRMIA provided polystyrene cuvets containing BiPO4+Pu+ZnS(Ag) precipitate showed no significant differences (P=0.83 unweighted, P=0.14 weighted). The samples were counted with the DRMIA alpha radiometer while USTUR chemically separated out the plutonium and counted it with the USTUR alpha spectrometer. The scatter plot (Figure A-1) showed no systematic differences in the results from the two laboratories.

A comparison of radiochemical analyses of 10 samples provided by DRMIA showed no significant differences in total plutonium counted (Figure A-2) among USTUR alpha spectrometry, DRMIA alpha spectrometry, or DRMIA radiometry (P=0.77 unweighted, P=0.47 weighted). No systematic differences among the three sets of data were observed in the scatter plots. The analyses of variance for ^{238}Pu, $^{239+240}$Pu, and ^{241}Am detected no significant differences for weighted or unweighted data (P>0.05). No significant differences were detected when comparisons were made with samples having values less than MDA removed. A comparison of DRMIA alpha spectrometry to DRMIA radiometry total plutonium and amercium results on eighteen samples, including the 10 previously mentioned, showed no significant differences either with or without values less than MDA removed (P>0.05).

Comparisons of ^{238}Pu measurements by DRMIA and USTUR alpha spectrometry of ten samples provided by USTUR showed no significant differences for unweighted (P=0.30) or weighted (P=0.82) analyses. When samples having values less than MDA were removed, differences in means were not significant. (P= 0.31 unweighted, P=0.98 weighted). Results were very similar for comparisons of $^{239+240}$Pu. However, comparison of ^{241}Am measurements (Figure A-3) indicated significant differences for the unweighted analysis (P=0.04) but not for the weighted analysis of variance (P=0.99). When one

sample with a value less than the MDA was removed the unweighted analysis remained significant (P=0.04) and the weighted analysis remained insignificant (P=0.46). Examination of the data and the scatter plot showed that in 7 of the samples the USTUR count was greater than the DRMIA count. The difference detected was approximately 5% of the overall mean of the samples.

Statistical power analyses were based on ten samples consisting of aliquots of dehydrated acid-dissolved tissues provided by DRMIA. These results indicate that ten samples are sufficient to detect a difference of 10% of the mean in total plutonium with a power of 85%. The power for detecting a difference of 10% of the mean for ^{238}Pu is only 50% and for $^{239+240}$Pu the power is 84%. Based on these samples the power for detecting differences of 10% of the mean for amercium is only 17% for a sample size of 10.

The third step was to have been accomplished during this reporting period; however, a problem was encountered. The SRM as well as standard radioactive solutions of plutonium, americium, thorium, and uranium isotopes, for calibration of newly acquired alpha spectrometer (see Task D, below), were purchased in the U. S. in April, 1998 and were to have been delivered to Ozyorsk. An obstacle developed as a result of unexpected changes in Russian regulations for import of radioactive materials and delivery of the materials was not completed. The new regulations state that the DRMIA now needs a license for receipt of all isotopes of plutonium, uranium, and thorium regardless of the quantity and obtaining that license will require much time and money. Therefore, the completion of the third step of Task A will be delayed for an indefinite period pending receipt of the necessary license..

The problem of clearance of radioactive shipments through Russian customs was discussed with representatives of the U. S. Department of Energy (DOE) during their visit in Ozyorsk in September, 1998. The possibility of assistance from the JCCRER or the possibility of delivery of such materials through the International Science Technical Center will be investigated. If these avenues are unsuccessful, it may be necessary to provide additional funding to the DRMIA for the licensing process.

Task B. Establishment of common database formats that will de available to both Registries for studies of actinide metabolism in personnel (Tasks F, G, H).

The main purpose of this task was to determine the format and structure of a database that could contain data of both Registries for use in performance of the biokinetic modeling tasks (Tasks F, G, and H). The database structure with descriptions of files were presented in a previous progress report (1 April 1997 - 30 September 1997). As expected, the structure was modified slightly to include "state of health" information on Registrants and this modification was described in the last progress report (1 October 1997 - 11 March 1998. Immediately previous to the SRG meeting in Chelyabinsk in April, 1997, selected numbers of DRMIA and USTUR cases were successfully merged into a

combined database. The database now contains exposure history, health information, and tissue and organ concentrations of plutonium from 295 DRMIA cases and 145 USTUR cases for a total of 440 cases. These data are currently in use in conjunction with Tasks F, G, and H. An example of the joint database with 5 DRMIA and 5 USTUR cases is included Table B-1 of this report.

Task D. Coordination of radiochemical methods to be used by each Registry to determine Pu and Am content of tissue samples.

This has been a high priority task with many accomplishments during the first 1.5 years of Project 2.1; some of those accomplishments are summarized here. During 1997 and 1998, the DRMIA significantly modernized their radiochemical analytical methods for measurement of plutonium and americium in biological samples. The DRMIA has converted to Bio-Rad anion exchange resins and the americium extractant, DDCP, for chemical separations of the actinides from biological samples and measured activity with their ionization chamber-based alpha spectrometer. These steps, alone, have decreased the minimum detectable activity (MDA) for plutonium and americium in samples from 0.005 to 0.002 Bq. An important comparison of the new and old methods was performed and it indicated no statistically significant differences in results obtained either way or with the results of the same samples analyzed at the USTUR laboratories.

The DRMIA has progressed toward the use of alpha spectrometry for routine measurement of actinides in biosamples. The have purchased an EG&G Ortec OCTETE PC alpha spectrometer with 16 chambers, each with a 450 mm^2 ULTRA surface barrier silicon detector. The instrument has a 24-25% detection efficiency, 25 keV resolution and integral and differential non-linearity less than 1%. For calibration of this alpha spectrometer, the DRMIA attempted to purchase NIST-certified Standard Radioactive Solutions of ^{239}Pu, ^{242}Pu, ^{241}Am, ^{243}Am, ^{232}U, ^{229}Th, and ^{238}Pu; however, the change in Russian customs regulations prevented their delivery. This necessitated calibration of the alpha spectrometer with $^{242}Pu + ^{239}Pu + ^{241}Am$ sources prepared and measured by DRMIA staff during their visit to DRMIA laboratories in December, 1997. The energy spectra of one of the sources is shown in Figure D-1.

It was decided that the system would be calibrated over an energy range of 3.5 - 6.0 MeV distributed over 512 channels. The calibration of each detector was performed using the above calibration sources measured for a period of 10,800 seconds with no fewer than 10,000 counts in each isotopic peak. The efficiency of the alpha spectrometer was calculated with the same measurements, using the gross alpha count in the peak for ^{241}Am (the highest activity in the mixture) and the efficiency was calculated to be $25 \pm 0.5\%$. The mean chamber background (without the disk) for the total energy range was fewer than three counts per day.

In July and August, 1998, the electrolysis unit for actinide electrodeposition from 0.75 M H_2SO_4 on polished stainless steel disks (diameter = 17.5 mm) was installed in the DRMIA laboratory. DRMIA staff members have performed preliminary tests to determine the chemical recovery of plutonium and americium, electroplated by the new method on planchets from Standard Radioactive Solutions and eluates after radiochemical separation of actinides in soft tissues as well as bone samples. Average recovery of the ^{242}Pu tracer was 67 $\pm$ 3.4% and the average recovery of the ^{243}Am tracer was 63 $\pm$ 3.3%. Figures D-2 and D-3 show the energy spectra of two of the samples.

Task E. Analysis of physico-chemical properties of workplace aerosols (such as particle size distribution and in vitro solubility) at the Mayak facility and American facilities for the purpose of more accurately predicting plutonium behavior in the lungs of workers.

The objective of this task, as stated in the original proposal, was to investigate the physico-chemical properties of workplace aerosols with respect to particle size distribution and solubility in body fluids. Knowledge of these properties would be very important to the characterization of aerosol clearance from the lung and dissolution in the systemic circulation. Because attempts to purchase a suitable cascade impactor with which to evaluate partical size distribution, the DRMIA team continues to study only the solubility characteristics of workplace aerosols.

The DRMIA uses a method called, "dialysis" for measuring the transportability (solubility) of workplace aerosols collected on air sampling filters with a resulting transportability coefficient "S", expressed as a percent. Details of the measurement method and the calculations performed to determine "S" were reported in the Journal of Radioanalytical and Nuclear Chemistry, vol 234, Nos. 1-2, 1998 by Khokhryakov et al.

Between 1974 and the present, approximately 300 air samples from workplaces in a uranium reprocessing plant and a plutonium production plant were analyzed by the DRMIA. Transportability coefficients of the aerosols in these plants varied about a mean value which was typical for a specific workplace. The data in table E-1 show a definite trend in the coefficients ranging from the highest solubility of aerosols collected from the initial stages of the process (dissolution of substrates in nitric acid) to the least soluble aerosols collected from the final stages (work with plutonium metal) at Mayak PA. Thus the values of S correlate well with the solubility of the plutonium compounds at each stage of the process and the mean transportability coefficients of aerosol samples ranged over one order of magnitude from the lowest to the highest. It is noted that, at each workplace, the variability of S values (standard deviation) is quite high. For example, there is typically a high variability in solubility of aerosols from the plutonium reprocessing plant. This can be explained by the presence of various chemical forms of plutonium at these workplaces. The establishment of an association between transportability coefficients and chemical forms of aerosols allows an extrapolation of the transportability data obtained after 1974 to previous times in the production cycle. Thus, knowing the

history of the technological processes used at each workplace should make it possible to predict the probable properties and, hence, the probable behaviour of alpha-active aerosols in the lungs and bodies of the personnel exposed by inhalation.

Another aspect of aerosol transportability has been evaluated by the DRMIA since the mid-1970's. The results of these evaluations indicate that plutonium distribution in the respiratory tract is correlated with the coefficient of transportability. To show those correlations, plutonium concentration ratios between organs of the respiratory tract and the systemic concentrations in individual cases were calculated. DRMIA cases were grouped according to exposure histories of the cases (ie: the most probable value of transportability of aerosols inhaled while the individual was alive, based on the individual's workplace). Geometric mean concentration ratios, with geometric standard deviations, were calculated for each group for the lungs, alone, the pulmonary lymph nodes, and for the lungs plus pulmonary lymph nodes (respiratory tract). The method of calculating the ratios are described in detail in the Task F progress report (below) and The data are shown in Table F-1 along with the transportability coefficient, S, for aerosols to which the groups were most likely exposed. The values in Table F-1 show a strong correlation between S values and the DRMIA mean ratios; the highest ratios are associated with the least soluble aerosols (smallest values of S). The information presented in this report as Task E and Task F progress lead to the conclusion that the transportability coefficient is a valuable tool for measuring the physico-chemical properties of workplace aerosols and it is useful for predicting the behavior of those aerosols in the respiratory tract.

Task F. Analysis of the dynamics of respiratory tract:systemic concentration ratios from data of both Registries for the purpose of establishing the lung clearance coefficients for plutonium compounds to the systemic circulation.

This task is devoted to the main issue of dosimetry by investigation of the clearance of plutonium industrial compounds from the respiratory tract into the blood of personnel exposed by inhalation.

During this reporting period, the correlation between the relative plutonium concentrations in the respiratory tract (the ratio of concentration in lungs and lymph nodes C_{resp} over mean systemic concentration C_{syst}) and the transportability coefficient, S, was investigated as were the dynamics of the C_{resp}/C_{syst} ratio over time between exposure and death (residence time), based on the joint data of both Registries.

These analyses were performed with the cases for which actinide concentration data for no fewer than 4 organs (lungs, tracheabronchial lymph nodes, liver and skeleton) were available in the joint database. The Pu concentrations in lungs of DRMIA cases varied between 10^{-1} and 10^{4} Bq/kg and, in lymph nodes, between 10^{1} and 10^{6} Bq/kg. In the USTUR cases, lung and lymph node concentrations ranged between 10^{-4} and 10^{4} Bq/kg and 10^{-2} and 10^{4} Bq/kg, respectively. The ratio C_{lung}/C_{syst} varied from 10^{-1} to 10^{3} and C_{ln}/C_{syst} varied from 10^{-1} to 10^{4} in cases of both the USTUR and the DRMIA.

The plutonium concentration in the system C_{syst} was calculated according to the equation:

$$C_{syst} = \frac{C_l \times M_l + C_{sk} \times M_{sk}}{0.867 \times (M_b - M_l - M_{ln})}$$

where: C_l, and C_{sk} were the actinide concentrations in liver and skeleton respectively (Bq/kg), M_l, M_{sk}, M_b, M_{lung}, and M_{ln} were the masses of liver, skeleton, whole body, lung and lymph nodes (kg). If the data were absent, the masses of organs and the whole body recommended by ICRP 23 for Reference man were used (M_l = 1.8 kg, M_{sk} = 10 kg, M_b =70 kg, M_{lung} = 1 kg, and M_{ln} = 0.02 kg).

The factor 0.867 is the fraction of the total systemic content that is in the liver and skeleton, based on five whole body donors to the USTUR [McInroy et al.1989].

In the Task E progress report (above) a correlation between aerosol transportability and plutonium distribution in the respiratory tract was suggested. Table F-1 contains geometric mean ratios (with standard deviations) of plutonium concentrations in organs of the respiratory tract relative to systemic concentrations together with mean transportability coefficients of aerosols to which each group of personnel were likely to have been exposed, based on their work histories. There is a marked inverse correlation between the relative plutonium concentrations in the respiratory tract and the transportability coefficient, S. The highest ratios are associated with the least soluble aerosols; as S increases by an order of magnitude, the geometric mean ratios decrease by an order of magnitude. Using that information for the DRMIA cases, it is possible to draw inferences about the solubilities of aerosols inhaled by USTUR cases. Ratios of the majority of USTUR cases fall between S values of 0.3% and 1.0% (Table F-1 and Figure 8) and it has been generally believed that most USTUR cases were exposed to oxides or less soluble forms of plutonium (Kathren et al. 1993); there is very little information about aerosol solubility in the USTUR database. The "combined" group in Table F-1 includes USTUR cases together with the S=0.3 and S=1.0 groups of the DRMIA and the geometric means for that group show that the USTUR cases are within the bounds of the two DRMIA transportability groups. Within the "combined" groups, the geometric mean ratios for lungs, alone, is 11.53 while the mean for the respiratory tract (lungs + lymph nodes) is 20.87, suggesting that the retention halftime for plutonium in the pulmonary lymph nodes is greater than that of the lung. The differences between geometric means for the lung:system ratios and the lymph node:system ratios also reflect the transportability differences in the inhaled aerosols.

Lung:systemic plutonium concentration ratios (C_{lung}/C_{syst}) were regressed against residence time to determine if the fraction of plutonium absorbed from the lungs into systemic circulation was dependent on the residence time or the transportability coefficients, S, of the inhaled aerosols. These regressions are shown in Figures 4-8 and, as expected, the ratios decreased with increased residence times. It was noted that the y-intercepts of the regression lines are inversely related to the aerosol transportability coefficients; this

reflects the same relationship between transportability and geometric means of the lung:system ratios shown in Table F-1. It is of interest to note that the slopes of all regression lines do not differ regardless of S-values. Apparently, accelerated lung clearance of more soluble aerosols is a short-term phenomenon and, over the long-term, the transportability of the aerosols had little effect on absorption from the lung into the systemic circulation.

Pulmonary:systemic concentration ratios were grouped according to "pathology" groups to determine the effect of disease on movement of inhaled material from the lung to systemic circulation. The criteria for "pathology" grouping are included in the discussion of Task G progress, below.

Geometric means of the C_{lung}/C_{syst}, C_{ln}/C_{syst}, and C_{resp}/C_{syst} plutonium concentration ratios, with geometric standard deviations (δ_g) are shown in Table F-2. The means in Table F-2 suggest that severe disease conditions affecting major organ systems might have an effect on the transfer of plutonium between the respiratory tract and systemic circulation when compared to healthy individuals; although the differences between means are not likely to be statistically significant. This issue will be explored further and reported in the next progress report.

Task G: Determine the relationships between actinide concentrations of organs of the body and between individual organs and total body burdens in healthy individuals as well as in those with health impairment, specifically those with liver diseases.

In addition to the lungs, the skeleton and liver are considered the high-risk sites for cancer induced by actinide elements because they are the mains sites of deposition of those elements once incorporated into the body. Biokinetic models to describe uptake translocation and retention of the actinides in the skeleton and liver were largely based on data from animal experiments with only limited data available from accidentally-exposed humans. The DRMIA and the USTUR, together, have large amounts of data with which to test previous biokinetic models and modify those models or construct new models, as necessary. The purpose of Task G is to compare actinide concentrations in many of the systemic organs of the body and use those comparisons as a basis for testing and/or reconstructing models such as those proposed by the ICRP (ICRP 1979; 1986; 1993).

One of the primary goals of Task G is to determine if health impairment affects the movement of actinide elements in the human body. Many former workers from plutonium production facilities develop serious disease conditions that eventually lead to death. Preliminary investigations by the DRMIA have shown that the temporal urinary excretion patterns of individuals in a diseased state, particularly those with diseases of the liver, differ from the excretion patterns of relatively healthy individuals. In previously published DRMIA data. the fraction of systemic plutonium excreted per day varied between $1.42 \pm 0.49 \times 10^{-5}$ day^{-1} for healthy workers to $3.74 \pm 2.43 \times 10^{-5}$ day^{-1} for workers with malignant tumors of various organs (Khokhryakov et al. 1994. Task G is intended to help

determine the basis for the differences in urinary excretion of plutonium that occur in healthy versus diseased individuals.

Tissue donors to the DRMIA and the USTUR have been classified into groups according to disease conditions that were present at the time of death. These are the "Health Groups" of the joint database and, previously in this report, they are referred to as "pathology groups"; this classification was originated by the DRMIA for their workers. The groups are:

Group 3—disease conditions of the liver, specifically liver cirrhosis, primary liver cancer, metastatic cancer from other sources which involve the liver and marked fatty degeneration of liver tissue,

Group 2—cases of death from malignant tumors which do not involve the liver although they may result in moderate fatty dystophy of the liver, and,

Group 3—relatively health individuals who died from accidents or from cardiovascular diseases with only slight changes in liver tissue.

Organs studied as part of this task include the skeleton, liver, spleen, testes, thyroid, kidneys, heart, and skeletal muscle. Plutonium concentration ratios (C_i/C_{syst}) were calculated for each of these organs and regressed against residence time to determine any time dependency of the relative concentrations (C_I = the plutonium concentration of the organ in question). Figures G-1 through G-4 show the regressions for C_{liver}/C_{syst}) in pathology groups 1 and 3. These figures show that the C_{liver}/C_{syst} and C_{skel}/C_{syst} ratios did not change appreciably with time and that was also true for the other organs studied, indicating that the geometric mean C_I/C_{syst}) ratios were a valid measure for comparing the organs. It was noted, however, that the pathology group 3 C_{liver}/C_{syst} were generally lower than those pathology group 1 and the pathology group 3 C_{skel}/C_{syst} ratios were generally higher than those of pathology group 1. Table G-1 contains the geometric means and standard deviations of C_i/C_{syst} for all organs studied grouped according to pathology groups. The mean ratios also indicate that group 3 C_{liver}/C_{syst} and C_{skel}/C_{Skel} ratios were lower and higher than those of the other two health groups, respectively. The difference between mean liver:system ratios for the combined USTUR and DRMIA data of groups 1 and 3 was statistically significant. This effect was not obvious in the ratios for the other organs and the very high standard deviations of those means would preclude any conclusions.

Another approach to analysis of the same data involved a direct comparison of the skeleton and liver plutonium concentrations. For this approach, skeleton:liver concentration ratios were regressed against residence time. It was considered that this direct comparison would have an advantage for these two organs over the C_i/C_{syst} approach because the skeleton and liver have, by far, the highest concentrations of plutonium and they would have a dampening effect on a ratio with both of them included in the denominator of the ratio. The regressions for the three health groups are shown in

Figures G-5 through G-8 and the parameters of the regression lines are included in Table G-2. Although the slopes of the regression lines are similar, none of them is significantly different from zero, indicating no time dependence. It was noted that the skeleton:liver ratios as well as the regression line in group 3 were generally greater than those of the other groups and this was reflected in the geometric mean ratios for those organs in Table G-1. This suggests that, in that group, plutonium was lost from the liver, gained by the skeleton, or both when compared to the other groups.

Analysis of these data will be continued into the next reporting period to determine whether or not any definite conclusions may be drawn and, therefore, to determine if liver diseases should be considered in dose assessment.

Task H. Quantitate the relationships between actinide contents of the lungs and body organs at autopsy and the long-term, temporal pattern of urinary excretion in healthy individuals and in health-impaired individuals.

As stated previously (Task G), the DRMIA has performed preliminary investigations in which urinary excretion rates for plutonium were compared to the results of tissue analytical results in healthy and in health-impaired individuals (Khokhryakov et al. 1994; Suslova et al. 1994). Task H represents an expansion of that work with more cases, including cases of the USTUR. The DRMIA has identified 192 of their autopsy cases for which urinary excretion data are available. Of those cases, 155 had daily urinary excretion levels of plutonium that were above their minimum detectable amount (MDA), which was 10 mBq. Because this is a retrospective study, each individual in the cohort did not receive an equal number of bioassays. The number of bioassays performed on individuals is shown in Figure H-1 and the number ranges from 1-13 with an average of 2.5 bioassays per individual.

The DRMIA calculated a systemic excretion factor, K_s, using the formula below, to compare the daily urinary excretion of plutonium with the systemic burden determined by tissue analyses.

$U_m/Q_c = K_s$ where,

U_m = the daily excretion of plutonium (dpm/day),
Q_c = the systemic burden of plutonium (dpm), and,
K_s = the fraction of systemic plutonium excreted/day (10^{-5} /day).

Figure H-2 shows the distribution of K_s among 27 relatively healthy individuals (health group 1). K_s is log-normally distributed with a geometric mean and geometric standard deviation of 1.89 ± 1.78 E-5/day.

The USTUR urinary excretion data are received from many different laboratories throughout the U. S. and they are reports in many different formats with a variety of units. Compiling these data into a single, uniform, useable format is a very labor intensive process which is currently in progress. When completed, work on Task H can be resumed to include USTUR data for both healthy and health-impaired individuals. The results will be included in the next progress report.

Task I. Enhance the sensitivity of the in vivo counter used by DRMIA and perform calibrations and intercomparisons with other, similar facilities, to make the facility more useful for more precise characterization of the intake and retention of actinide elements by Mayak personnel.

This task has been modified since it was included in the original proposal of work. The DRMIA will soon receive modern in-vivo counting instrumentation and associated shielding from the Rocky Flats Plant in Denver, Colorado.

The following is a chronology of past and future events associated with Task I:

1. An agreement was reached with the International Scientific Technical Center to provide for clearance through customs and transportation for the Rocky Flats whole-body counter. This agreement greatly reduced shipment expenses and was reached through the efforts of E. Melamed, U. S. DOE.
2. Construction of a new facility at FIB-1 was completed by mid-September, 1998.
3. Because delivery of the shield was delayed, it was decided to construct a temporary roof over the building. When the shield is delivered, the temporary roof will be disassembled and, after installation of the shield, a permanent roof will be constructed which will require some additional funding. The price of transportation and installation of the whole-body counter is estimated at $25,000.00.
4. Assembling of the shield will be performed under the leadership of personnel from LLNL in October-November, 1998.
5. Assembling the instrumentation (detectors and computer system) will be performed by D. Hickman, LLNL, jointly with the Russian specialists at FIB-1. This is anticipated to occur in early 1999.

After the facility is operational, Project 2.1 personnel will provide for shipment of appropriate phantoms and assist the Russian specialists with calibration of the instrumentation. The completion of this task is planned for May, 2000.

Milestones and deliverables

Milestones of the proposed work consist of the completion tasks, as scheduled, and the semi-annual progress reports on the tasks in progress and those completed. The scheduled initiation and completion of tasks is attached to this report.
Tasks scheduled for completion during FY 1998:

Task A--1 April 1998 and
Task B--1 December 1997.
Progress reports scheduled for April, 1998 and October 1998.
Tasks scheduled for initiation during FY 1998:
Task F--1 December 1997,
Task G--1 December 1997,
Task H--1 April 1998.

Other Relevant Information, Including Relevant Trip Reports, Obstacles to Completion of Work Outlined in FY Work Proposal, Unexpected Costs

During the current reporting period, two meetings of Russian scientists and Ron Filipy, Principal investigator of the project from the USTUR, took place in Ozersk in April and September, 1998. Scheduled tasks were discussed and progress reports were drafted during these meetings.

In April 1998 much attention was given to discussion of issues regarding the organization of a joint database, necessary for performance of current tasks involving actinide biokinetics. It was decided that, with the goal of studying and making more precise some Pu metabolic parameters for healthy people and health-impaired individuals, the pathologic-anatomic diagnosis information regarding health states and causes of death were to be evaluated, especially cases with specific diseases that can lead to marked dystrophy of liver.

During the last visit(September, 1998) the information obtained was discussed and data (concentration in organs, standard deviation, diseases) of the both Registries were combined and entered into joint database. Thus, all information necessary for the progress report was prepared.

At the meeting with DOE representatives L. White and R. Neta in September 1998, obstacles to completion of work outlined in work proposal were discussed. It was with regard to Tasks A and D which were delayed due to changes in custom regulations of RF. To complete these tasks, the DRMIA purchased the Standard Reference Materials of organs and Standard Radioactive Solutions of Pu, Th, U isotopes, prepared by National Institute of Technology. It was noted that, to obtain a state license for import of radioactive materials to Russia, the DRMIA will need additional funds - approximately 5000 $.

Publications and Preprints

During 1998 year two progress reports were issued in English and in Russian :

1. Progress Report Number 3 for the period 1 February 1997 - 30 September 1997
2. Progress Report Number 4 for the period 1 October 1997 - 30 March 1998

Four articles were published in 1998 :

1. Filipy, R.E.; Khokhryakov, V.F.; Suslova, K.G.; Romanov, S.A.; Stuit, D.B.; Aladova, E.E.; Kathren. R.L. Analysis for Actinides in Tissue Samples from Plutonium Workers of Two Countries. Journal of Radioanalytical and Nuclear Chemistry 234(1-2): 171-174; 1998.

2. Khokhryakov, V.F.; Suslova, K.G.; Tsevelyova I.A.; Aladova, E.E.; Filipy, R.E. Classification of Alpha-Active Workplace Aerosols Based on Coefficient of Transportability, Measured by Dialysis Method. Journal of Radioanalytical and Nuclear Chemistry 234(1-2): 209-212; 1998.

3. Khokhryakov, V.F.; Kudryavtseva T.I.; Chernikov V.I.; Suslova, K.G.; Orlova, I.A.; Filipy, R.E. A Scintillation Method for Determination of Actinide-Alpha Activities in Samples. Journal of Radioanalytical and Nuclear Chemistry 234(1-2):293-295; 1998.

4. Khokhryakov V.F.; Suslova K.G.; Tseleva I.A.; Aladova Ye.Ye. Objective Method for Classifying Alpha-Active Aerosols for Dosimetry of Internal Irradiation. Medical Radiobiology and Radiation Security 4:41-45;1998.

At a joint meeting of Russian and American Scientific Review Groups in Chelyabinsk (14-16 of April 1998) three oral presentations were represented:

1. Ron E. Filipy Overview of Project 2.1 objectives.
2. V.F. Khokhryakov. About State of Scientific Research on Project 2.1
3. K.G. Suslova, I.A. Orlova, D.B. Stuit, S. Glover, T.I. Kudruavtseva . Results of interlaboratory comparison of radiochemical methods used by DRMIA and USTUR for analysis of tissue samples on Pu and Am content.

References

1. Suslova, K.G.; Filipy, R.E.; Khokhryakov, V.F.; Romanov S.A.; Kathren, R.L. Comparison of the Dosimetry Registry of the Mayak Industrial Association and the United States Transuranium and Uranium Registries: A preliminary report. Radiat. Protect. Dosim. 67:13-22;1996.

2. Filipy. R.E.; Khokhryakov, V.F. Annual Work Proposal Office of International Health Programs (EH-63) U.S. Departament of Energy. Project 2.1 "Dosimetry and Metabolism Industrial Compaunds". 1997.

3. Khokhryakov, V.F.; Suslova, K.G.; Aladova, E.E.; Orlova, I.A.; Chernikov V.I.; Filipy, R.E.; Stu it, D.B.; Glover, S.E.; Filby, R.H.; Kathren, R.L. Progress report number 3, Project 2.1 - Metabolism and Dosimetry of Plutonium Industrial Compounds. 1 February - 30 September 1997. USTUR-0089-97; 1997.

4. Khokhryakov, V.F.; Suslova, K.G.; Aladova, E.E.; Orlova, I.A.; Chernikov V.I.; Filipy, R.E.; Stuit, D.B.; Glover, S.E.; Filby, R.H.; Kathren, R.L. Progress report number 4, Project 2.1 - Metabolism and Dosimetry of Plutonium Industrial Compounds. 1 October - 10 March 1998.

5. Khokhryakov, V.F.; Suslova, K.G.; Tsevelyova I.A.; Aladova, E.E.; Filipy, R.E. Classification of Alpha-Active Workplace Aerosols Based on Coefficient of Transportability, Measured by Dialysis Method. Journal of Radioanalytical and Nuclear Chemistry 234(1-2): 209-212; 1998.

6. Khokhryakov, V.F.; Menshikh Z.S.; SuslovaK.G. ; Kudryavtseva, T.I.; Tokarskaya, Z.B.; Roma nov, S.A. Plutonium excretion model for the healthy man. Rad. Protect. Dosim. 53:235-239; 1994.

7. Suslova K.G.; Khokhryakov V.F. Urinary Excretion Rate of ^{241}Am by Occupationally exposed Workers of Radiochemical Plant. In: Health Effectc of internally deposited radionuclides. 121-124;1994.

8. International Commission on Radiological Protection. Reference Man: Anatomical, Physiological and Metabolic Characteristics. Oxford: Pergamon Press; ICRP Publication 23; Ann. ICRP 1975.

9. McInroy, J.F.; Kathren, R.L.; Swint,M.J. Distribution of Plutonium and Americium in Whole Bodies Donated to the United States Transuranium Registry. Rad. Protect. Dosim. 26(1/4):151-158; 1989.

10. International Commision on Radiation Protection. Limits for Intakes of Radionuclides by Workers, Part 1. Oxford: Pergamon Press; ICRP Publication 30; Ann. ICRP, 1979.

11. International Commission on Radiological Protection. The Metabolism of Plutonium and Related Elements Oxford: Pergamon Press; ICRP Publication 48; Ann. ICRP 1986.

12.International Commission on Radiological Protection. Age-dependent doses to members of the public from intake of radionuclides, Part 2. Oxford: Pergamon Press; ICRP Publication 67; Ann. ICRP 23(3/4): 1-167; 1993.

13. Kathren, R. L.; Strom, D. J.; Sanders, C. L.; Filipy, R. E.; McInroy, J. F.; Bistline, R. E. Distribution of plutonium and americium in human lungs and lymph nodes and relationship to smoking status. Rad. Protect. Dosim. 48:307-315; 1993.

14. Filipy, R. E. and Kathren, R. L. Changes in soft tissue concentrations of plutonium and americium with time after human occupational exposure. Health Physics 70: 153-159; 1996.

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Table B-1. Example of Project 2.1 database to be used for tasks involving biokinetic modeling.

Case No.	T(D)	Age(yr)	T(B)	T(E)	T(A)	RT (yr)	Health	Liver (Bq/Kg)	Liver SD	Skeleton (Bq/Kg)	Skeleton SD
DRMIA											
9	1986	58	1959	1979	1974	27	1	538.17	41.24	175.58	15.22
103	1994	66	1949	1974		45	3	50.62	3.91	81.73	8.28
383	1986	64	1949	1967		37	2	25.23	1.99	7.77	2.82
506	1981	44	1960	1964		21	3	27.94	2.18	19.93	4.15
627	1992	62	1958	1992		34	3	26.23	2.04	25.60	3.60
USTUR											
0049	1973	51	1961	1973		8	2	1.23		0.18	
0060	1975	51	1945	1946		30	1	37.79	1.15	6.14	
0141	1980	59	1944	1979		24		230.49	8.48	23.46	
0203	1983	62	1950	1971	1969	14	2	0.35	0.02	0.34	
0209	1984	73	1950	1977		25	3	1.61	0.05	0.21	

Key

T(D) = year of death
Age = age at death
T(B) = year of beginning work with actinide elements
T(E) = year of ending work with actinide elements
T(A) = year of incident or accident resulting in intake of actinide elements
RT(1) = residence time (time between exposure or potential exposure and death
Health = state of health at time of death
- 3 = impaired liver function by tumor, degeneration, etc.
- 2 = others health problems with no liver involvement
- 1 = essentially healthy individuals

Table B-1 (continued)

Lung (Bq/Kg)	Lung SD	Lymph Node (Bq/Kg)	Lymph Node SD	Spleen (Bq/Kg)	Spleen SD	Testes (Bq/Kg)	Testes SD
DRMIA							
1,777.82	90.29	39,135.06	3,013.50			15.13	1.64
105.59	8.17	12,681.01	976.24	19.02	1.65		
13.45	1.48	655.90	55.77	1.67	0.48		
43.30	3.76	15,720.91	1,236.42	7.40	0.77	3.70	1.11
33.68	2.61	1,841.42	145.67	4.37	0.75	1.18	1.18
USTUR							
9.60		6.76		0.06		0.06	
383.06	15.14			3.98	0.10	0.89	0.07
877.88		2,623,414.86	4,284.26	67.69	2.39	4.38	0.22
0.47	0.03	84.40	11.40	0.42	0.03	0.05	0.02
3.08	0.10	73.75	2.23	0.09	0.01	0.03	0.01

Table B-1 (continued)

Thyroid (Bq/Kg)	Thyroid SD	Kidney (Bq/Kg)	Kidney SD	Heart (Bq/Kg)	Heart SD	Muscle (Bq/Kg)	Muscle SD	Ovaries (Bq/Kg)	Ovaries SD	Urine (Bq/Kg)	Urine
DRMIA											
10.92	2.35	7.07	0.67	4.22	0.60	2.52	0.28				
11.95	4.34	2.85	0.40	3.03	0.50	1.59	0.50	8.73	3.34		
		0.41	0.11	0.11	0.12	0.19	0.12				
5.03	1.42	3.18	0.50	0.81	0.47	0.41	0.09				
0.67	0.49	1.04	0.59	0.62	0.14						
USTUR											
0.01		0.03		0.02							
1.42	0.09	0.55	0.02			1.15	0.03				
1.84	0.16	1.37	0.07	0.95	0.04	2.23	0.06				
0.04	0.02	0.02	0.01			0.12	0.04				
0.03	0.02	0.02	0.003			0.07	0.01				

Table E-1. Correlation of the transportability coefficient and chemical form of workplace plutonium compounds.

Plant	Predominant chemical form of the process substrate	Mean transportability coefficients S $\pm$ SD (%)
Reprocessing uranium fuel	nitrate	2.14 $\pm$ 0.43 to 4.60 $\pm$ 2.4
Plutonium processing (1)	nitrate, chloride, oxalate, dioxide	0.56 $\pm$ 0.21 to 2.60 $\pm$ 0.53
Plutonium processing (2)	metallic form	0.15 $\pm$ 0.08 to 0.37 $\pm$ 0.20

Table F-1. Geometric mean plutonium concentration ratios of organs of respiratory tract: System grouped on the basis of the transportability coefficient of inhaled aerosols.

Registry	S	Lung			Lymph. Nodes			Respiratory Tract		
		N	GM*	σg	N	GM	σg	N	GM	σg
DRMIA	0.3	45	26.4	2.46	45	1051.76	3.46	45	55.48	2.28
	1.0	100	6.93	2.40	95	289.78	3.42	92	14.90	2.31
	3.0	96	2.15	2.07	94	46.20	3.66	90	3.26	2.24
USTUR	-	112	13.03	5.54	70	114.12	8.02	59	16.75	5.36
Combined		257	11.53	4.02	210	279.99	5.79	196	20.87	3.55

* GM – geometric mean

Table F-2. Geometric mean plutonium concentration ratios of organs of the respiratory tract: system, grouped by health state of the individuals.

Organ	Health	DRMIA, w/o S=3.0			USTUR			Combined		
		N	GM	σg	N	GM	σg	N	GM	σg
Lung	1 2 3	49	13.14	2.62	6	55.47	3.48	55	15.37	2.96
		53	9.55	2.70	71	10.82	5.72	124	10.25	4.34
		43	9.14	3.54	35	14.82	5.04	78	11.35	4.24
Lymph Nodes	1 2 3	49	368.05	4.69	3	214.39	6.94	52	356.75	4.73
		49	484.06	3.52	44	112.46	7.82	93	242.65	6.22
		42	479.50	3.62	23	108.11	9.22	65	283.06	6.10
Resp. Tract	1 2 3	49	24.55	2.75	2	63.14	2.50	51	25.48	2.77
		48	21.58	2.70	39	15.32	5.63	87	18.51	3.95
		40	22.73	3.10	18	17.54	5.10	58	20.97	3.66

Table G-1. Geometric mean plutonium concentration ratios of organ: system, grouped by health state of the individuals.

Organ	Health		DRMIA		USTUR			Combined		
		N	Geom. mean	SD	N	Geom mean.	SD	N	Geom. Mean	SD
Liver	1	75	14.03	1.315	7	19.95	1.23	82	14.45	1.33
	2	103	10.30	1.626	77	13.55	2.21	180	11.59	1.91
	3	77	4.30	1.782	40	10.26	2.21	117	5.78	2.17
Skeleton	1	75	3.30	1.216	7	2.61	1.21	82	3.24	1.23
	2	103	3.84	1.253	78	3.03	1.59	181	3.47	1.44
	3	77	5.07	1.086	42	3.61	1.41	119	4.50	1.31
Spleen	1	67	0.54	1.914	7	2.48	2.24	74	0.62	2.22
	2	85	0.72	1.991	65	1.18	2.64	150	0.89	2.35
	3	68	0.86	2.051	34	1.90	2.24	102	1.13	2.31
Testes	1	31	0.47	1.799	2	0.58	1.60	33	0.47	1.78
	2	43	0.55	1.714	47	0.51	2.12	90	0.53	1.93
	3	32	0.94	1.637	19	0.95	4.67	51	0.94	2.72
Thyroid	1	33	0.26	1.774	2	1.92	4.47	35	0.29	2.16
	2	46	0.29	1.832	42	0.32	2.57	88	0.30	2.18
	3	46	0.38	2.046	29	0.71	4.50	75	0.48	3.08
Kidneys	1	68	0.25	1.871	6	0.58	2.61	74	0.27	1.99
	2	87	0.26	1.710	67	0.28	2.40	154	0.27	2.02
	3	69	0.25	1.622	38	0.37	3.85	107	0.29	2.47
Heart	1	69	0.15	1.982	4	0.33	1.95	73	0.16	2.02
	2	81	0.18	1.663	16	0.39	3.75	97	0.20	2.14
	3	70	0.21	1.462	11	0.30	6.37	81	0.22	2.12
Muscle	1	67	0.08	2.355	2	0.11	9.57	69	0.08	2.43
	2	80	0.10	1.854	13	0.21	2.92	93	0.11	2.10
	3	69	0.11	1.556	12	0.65	10.16	81	0.14	3.14

Table G-2. Parameters from the regression lines relating skeleton:liver plutonium concentration ratios to residence times (Figures G-5 through G-8).

Health Group	Number of cases	Slope	SE[a]	P[b]	Y-intercept	SE
1	78	0.005	0.002	0.052	-0.78	0.064
2	163	-0.005	0.004	0.18	-0.39	0.11
3	108	0.001	0.004	0.73	-0.13	0.13

[a]Standard error
[b]Probability that the slope is not significantly different from zero

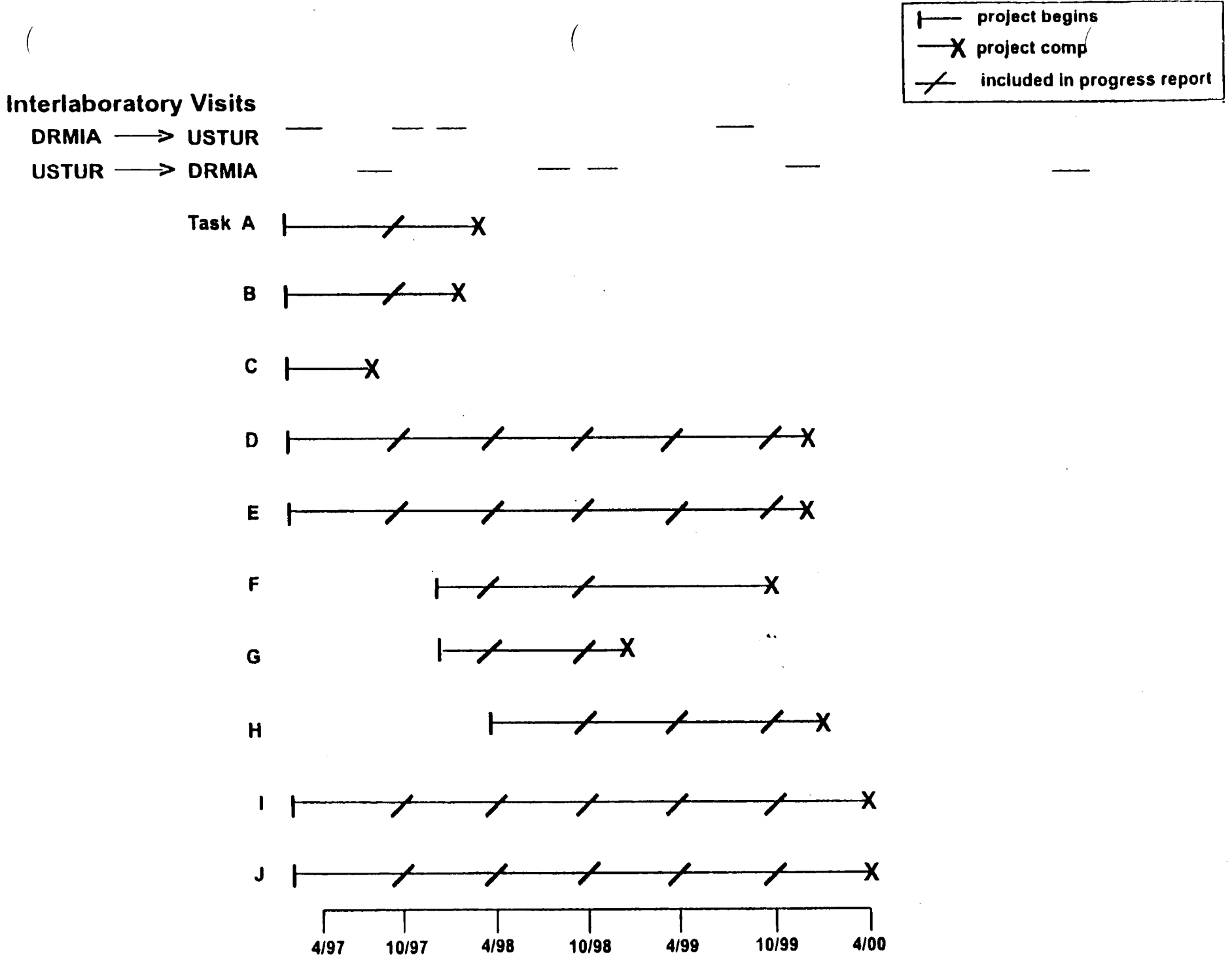

Figure 1. Schedule of Proposed Tasks

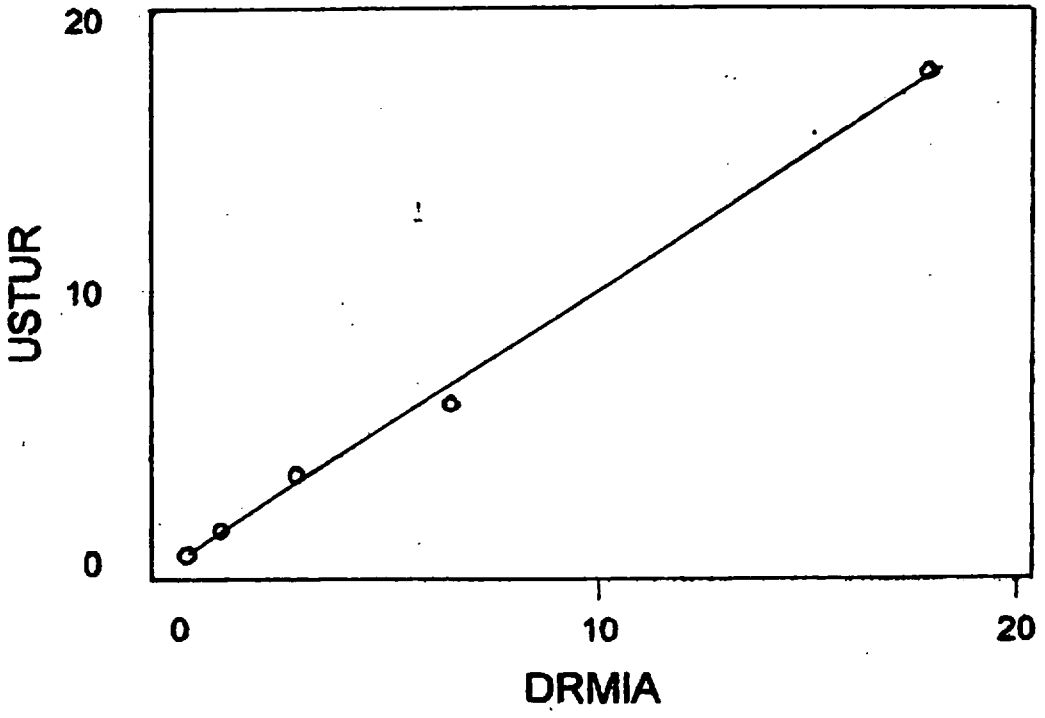

Figure A-1 Comparison of the results of USTUR alpha spectrometry and DRMIA alpha radiometry on samples prepared by DRMIA. Samples were plutonium in $BiPO_4$ in ZnS(Ag) scintillation powder.

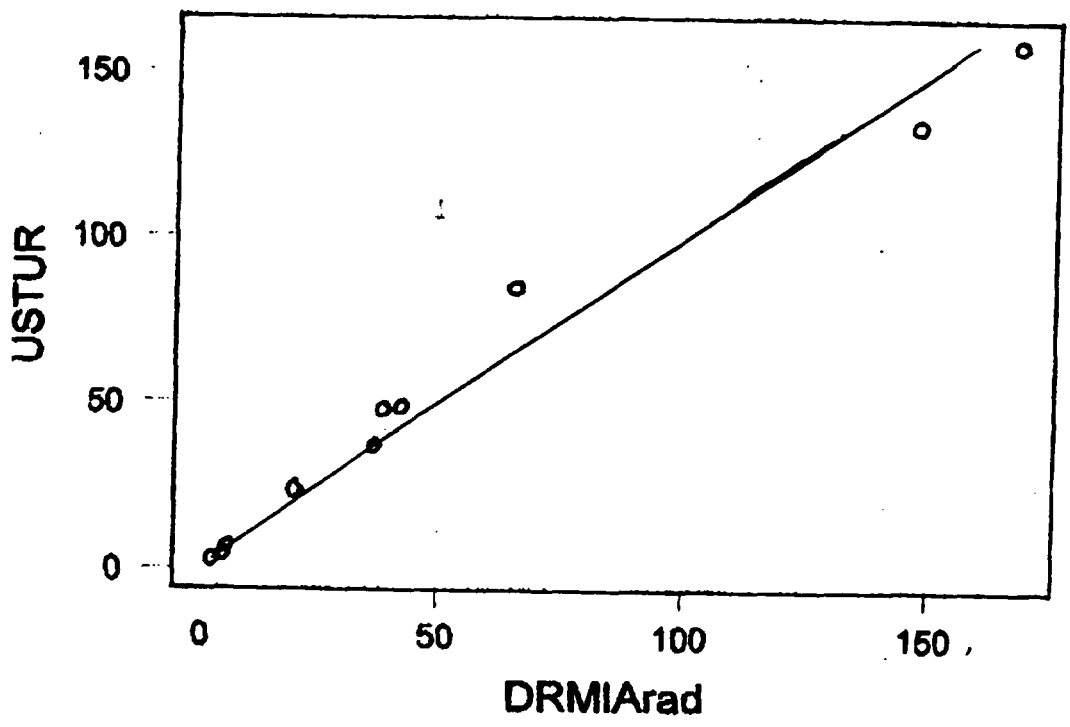

Figure A-2. Comparison of measurements of total plutonium in samples prepared by the DRMIA and measured by alpha radiometry with USTUR alpha spectrometry. Samples were aliquots of dehydrated acid-dissolved tissue solutions or bone ash.

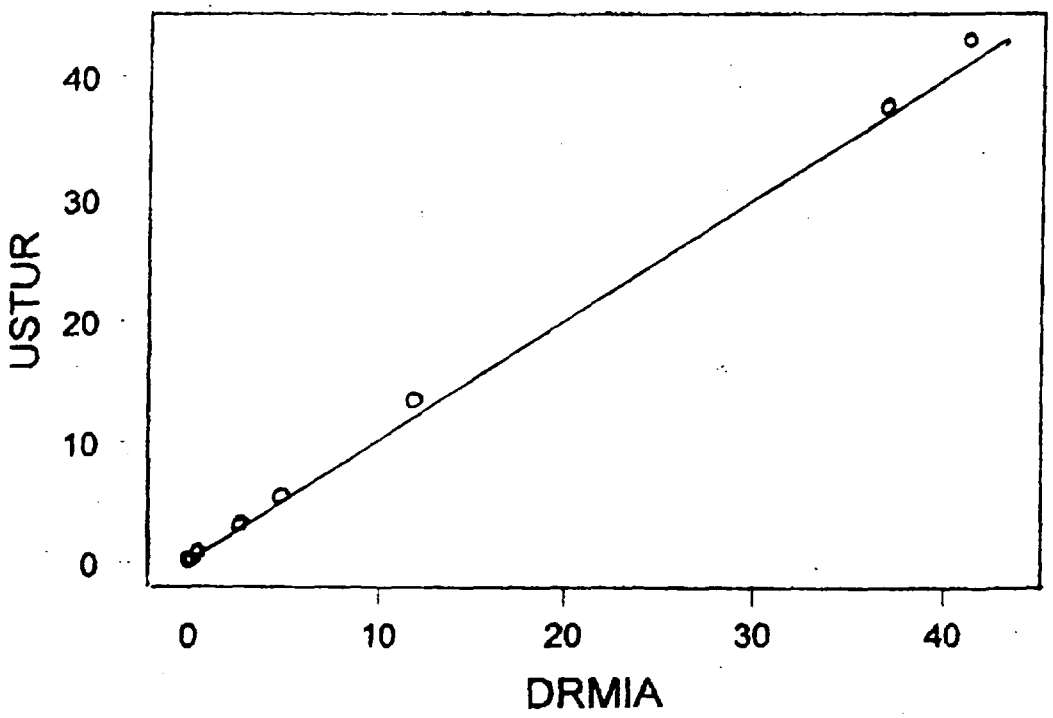

Figure A-3. Comparison of USTUR and DRMIA alpha spectrometry on samples prepared by the USTUR. Samples were americium in aliquots of dehydrated Acid-dissolved tissue sections or bone ash.

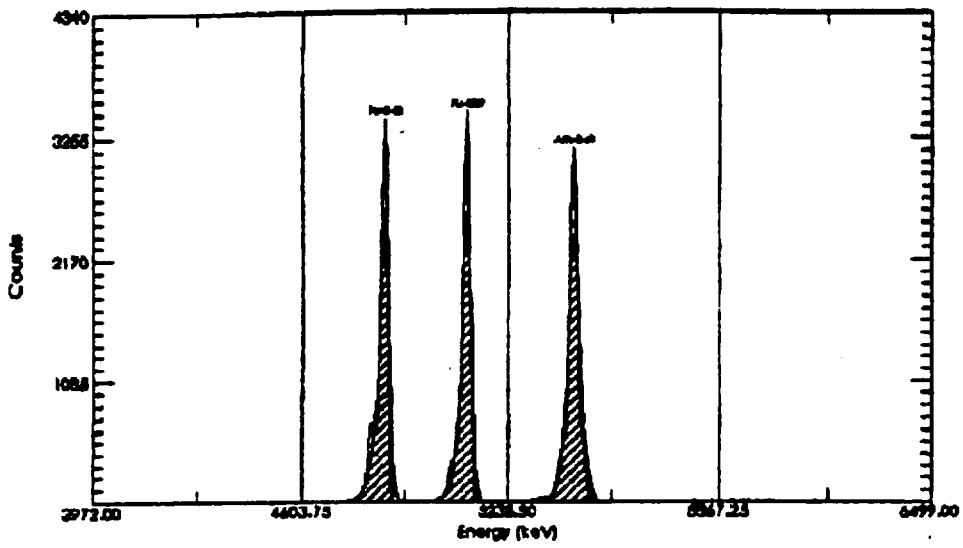

Figure D-1. The spectrum of isotopes of secondary standard source $^{242}u + ^{239}Pu + ^{241}Am$ used for energy calibration of the DRMIA Ortec alpha spectrometer.

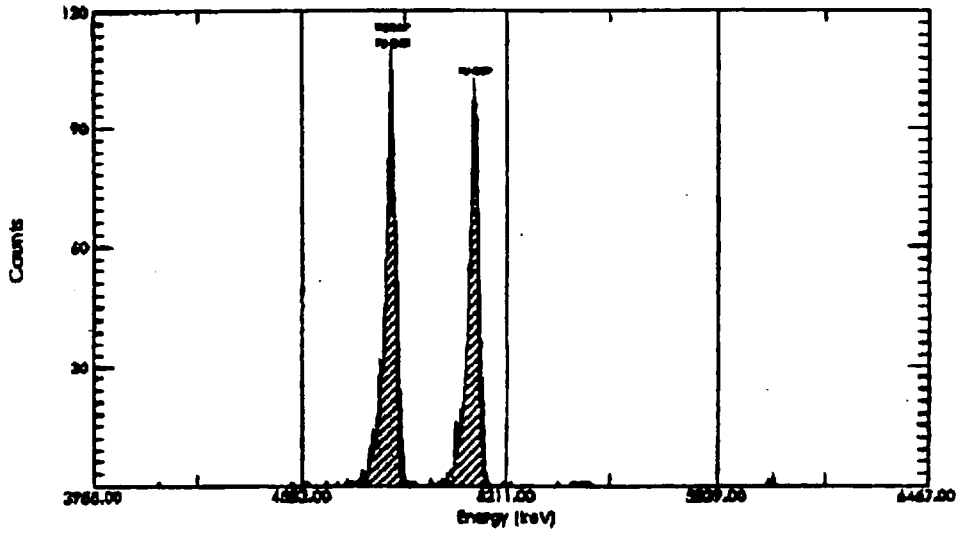

Figure D-2. The energy spectrum of plutonium isotopes in a lung sample.

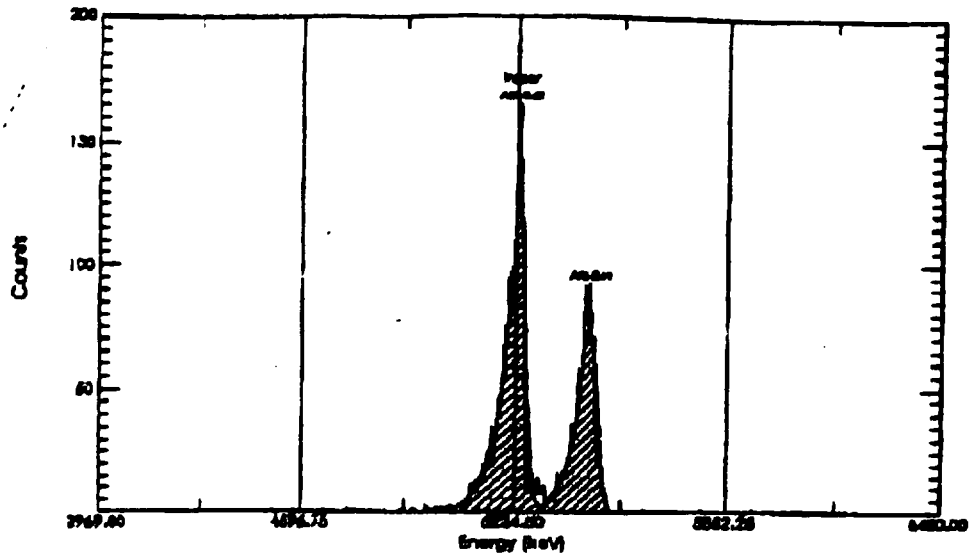

Figure D-3. The energy spectrum of americium isotopes in a rib sample.

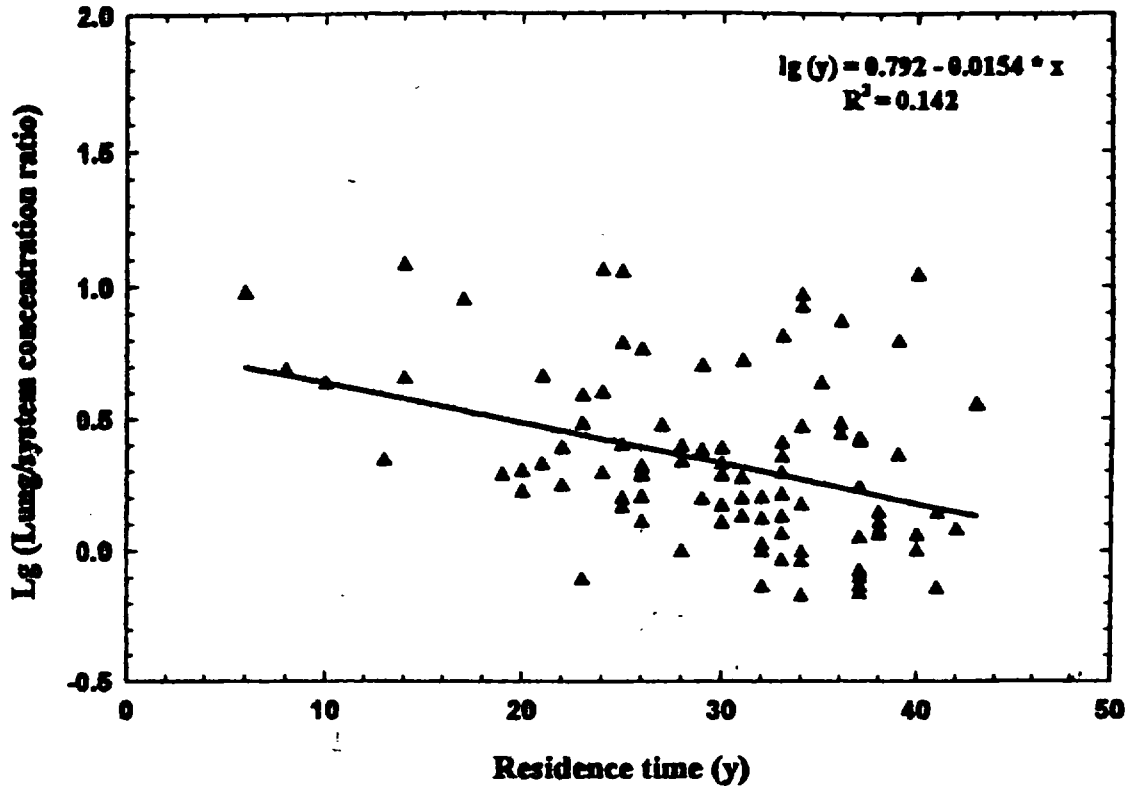

Figure F-1. Lung: system plutonium concentration ratios as function of time between exposure and death (residence time) in DRMIA cases, S = 3.0%

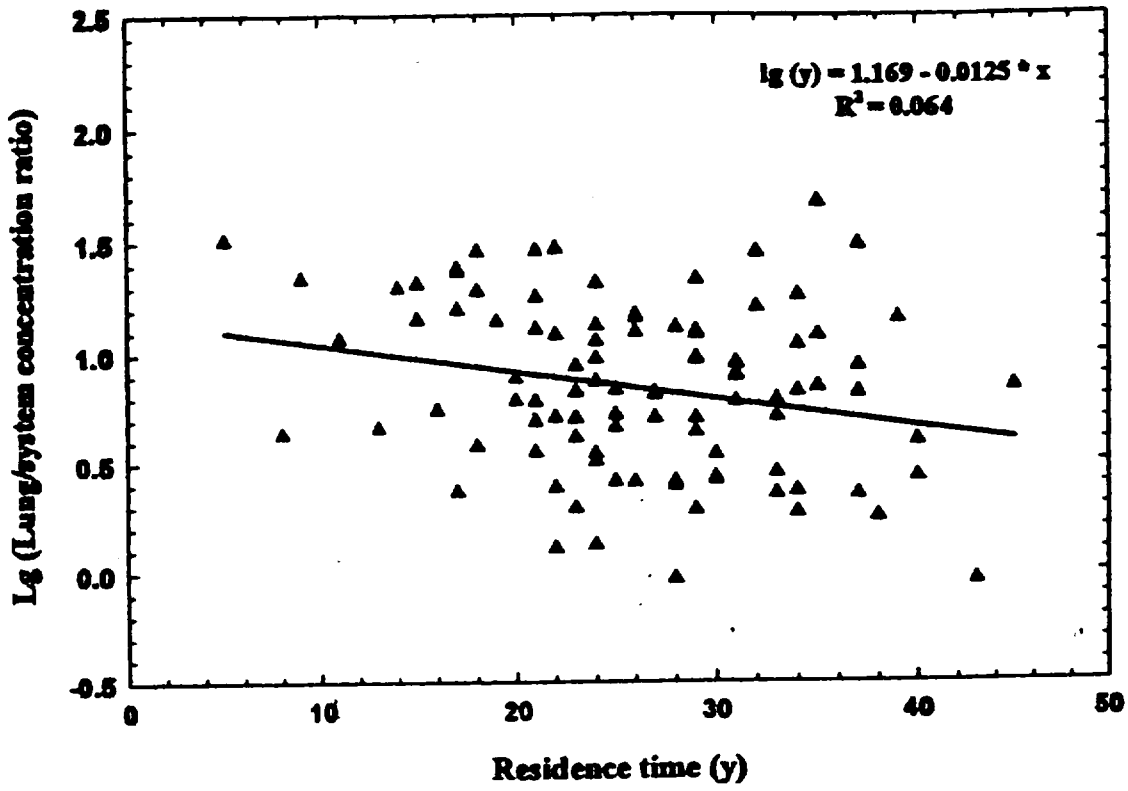

Figure F-2. Lung: system plutonium concentration ratios as function of time between exposure and death (residence time) in DRMIA cases, S = 1.0%

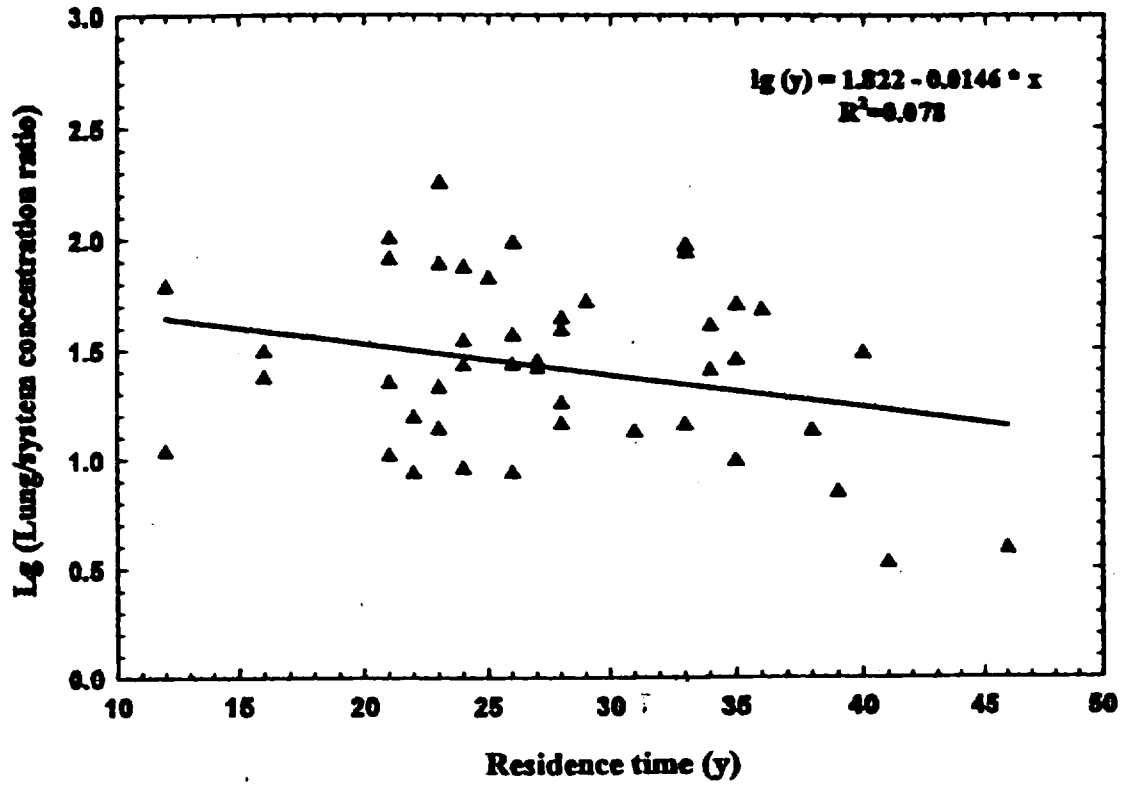

Figure F-3. Lung: system plutonium concentration ratios as function of time between exposure and death (residence time) in DRMIA cases, S = 0.3%

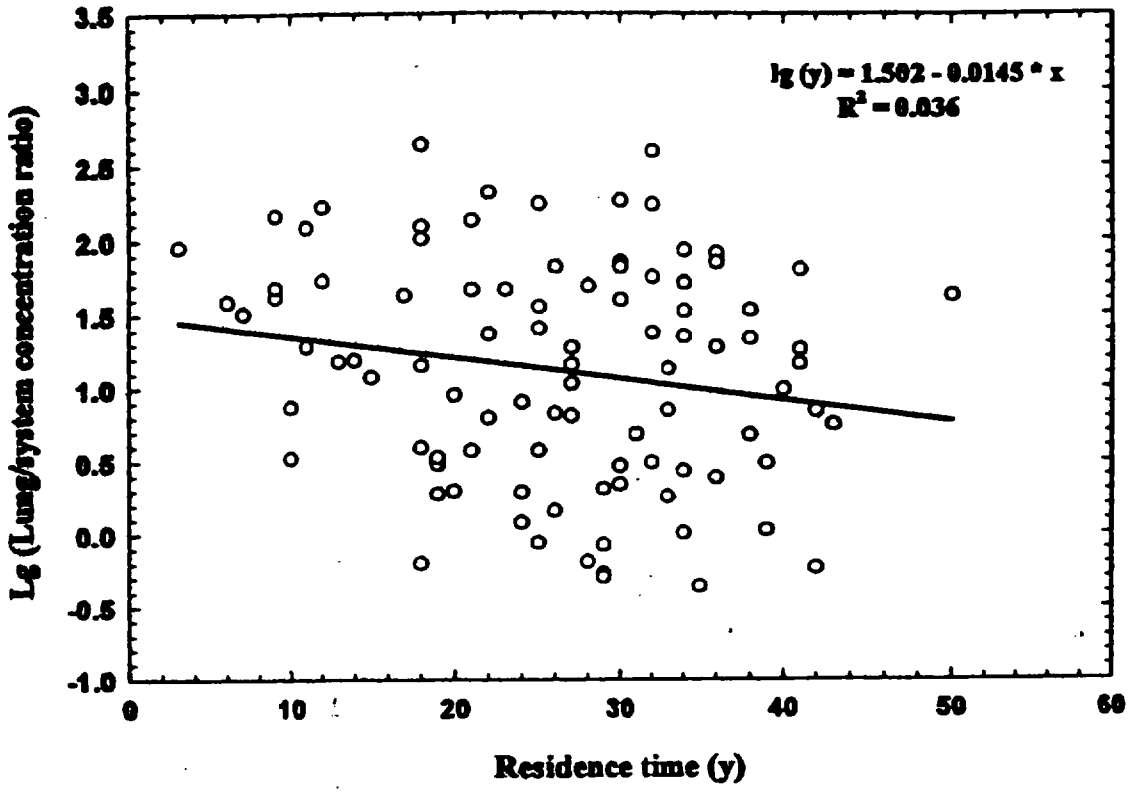

Figure F-4. Lung: system plutonium concentration ratios as function of time between exposure and death (residence time) in USTUR cases

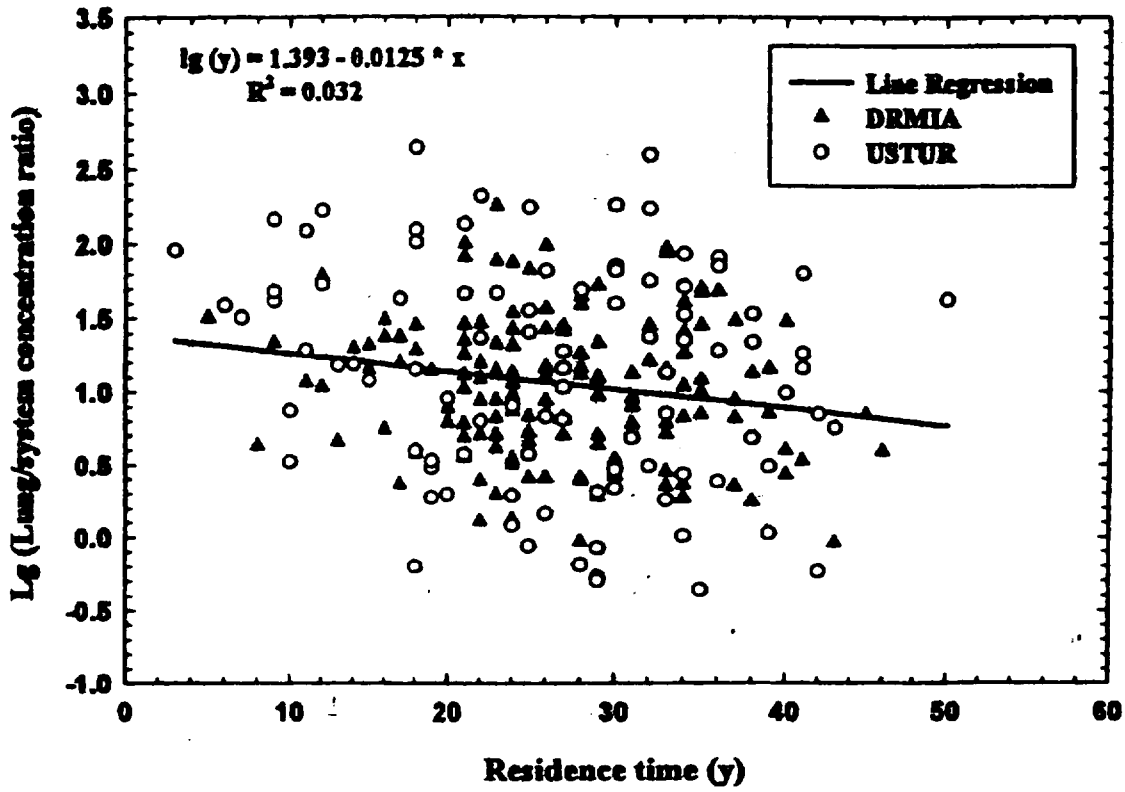

Figure F-5. Lung: system plutonium concentration ratios as function of time between exposure and death (residence time) in DRMIA (S = 0.3% and S = 1.0%) and USTUR cases

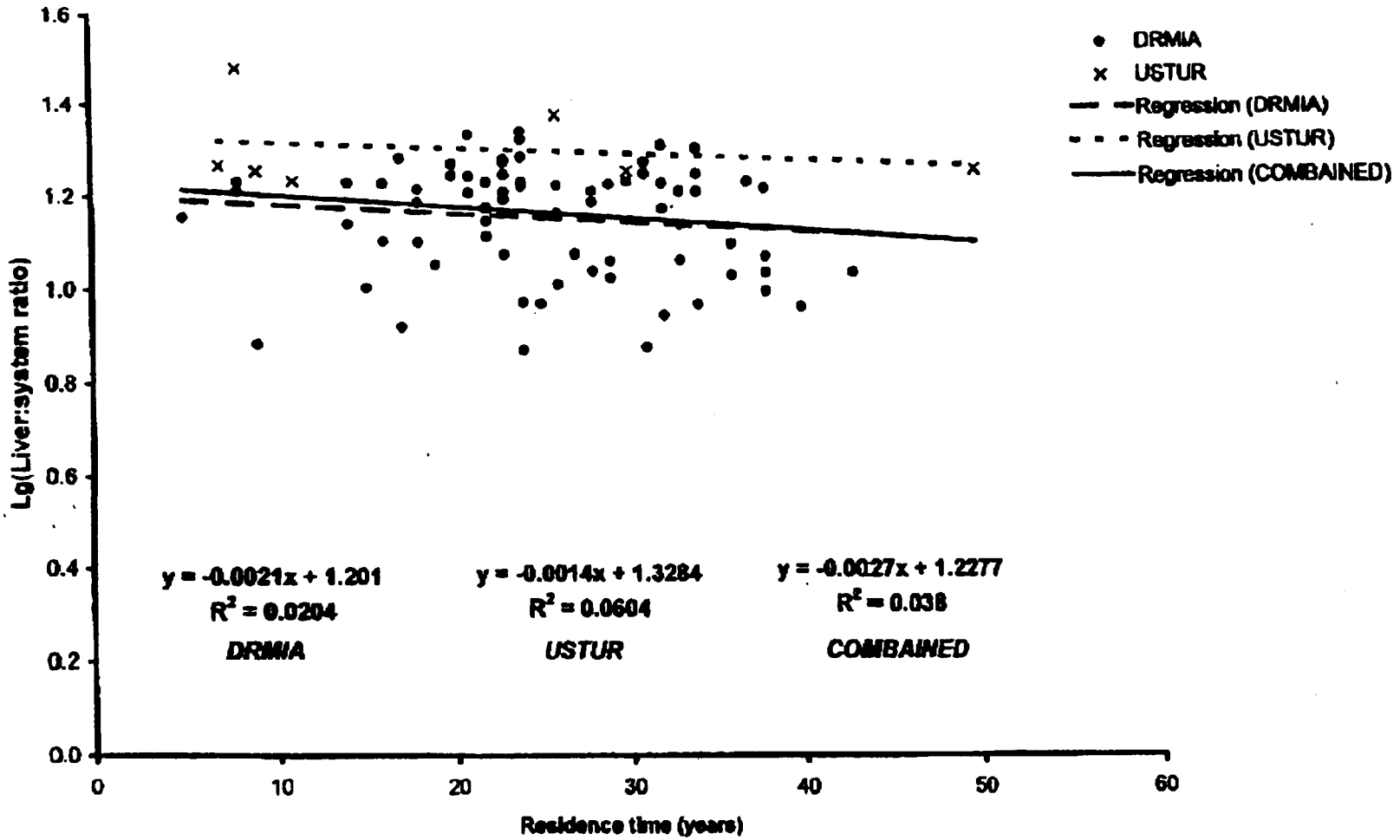

Figure G-1. Liver: System plutonium concentration ratios as a function of residence time for healthy people (patology group 1)

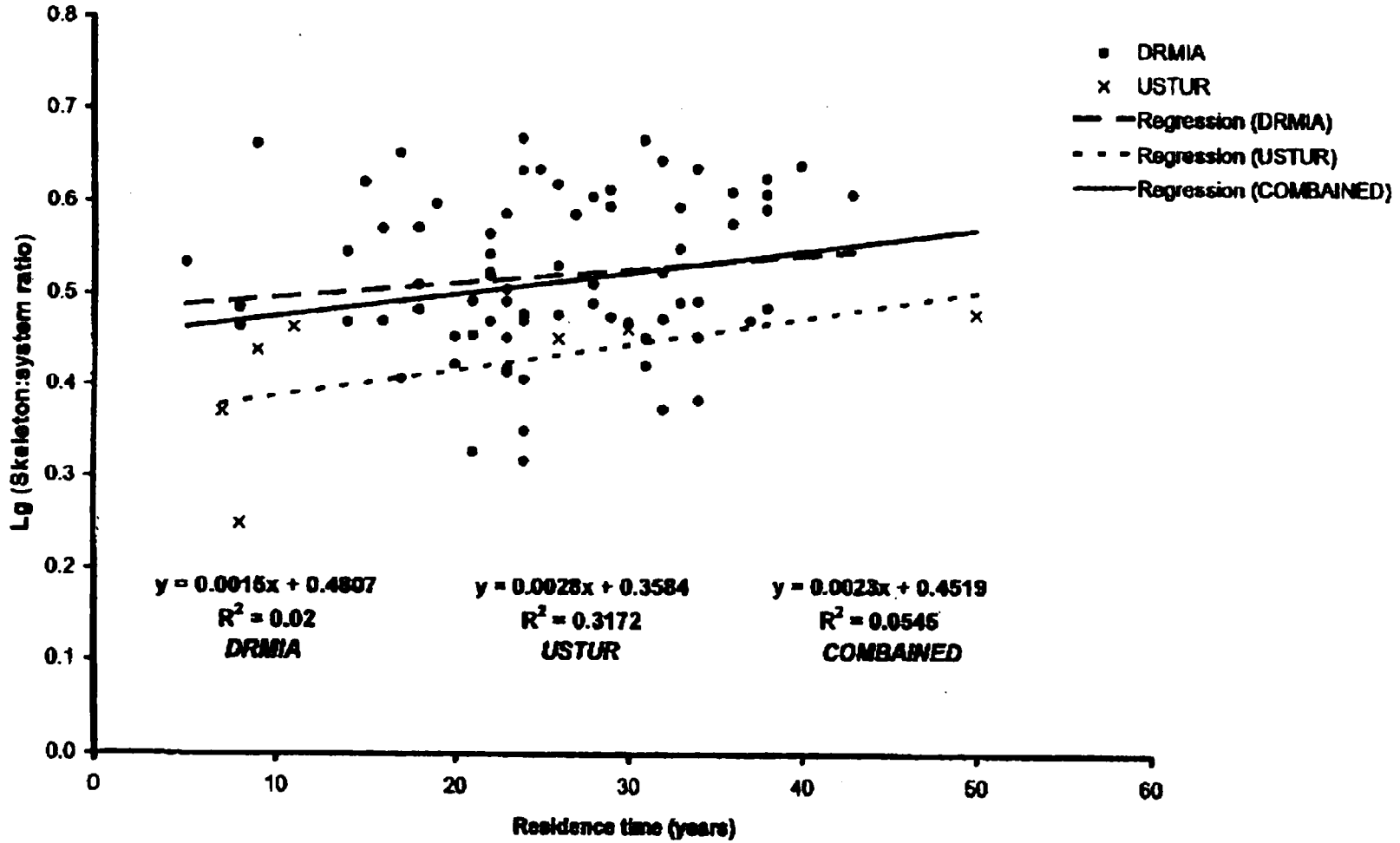

Figure G-2. Skeleton: System plutonium concentration ratios as a function of residence time for healthy people (patology group 1)

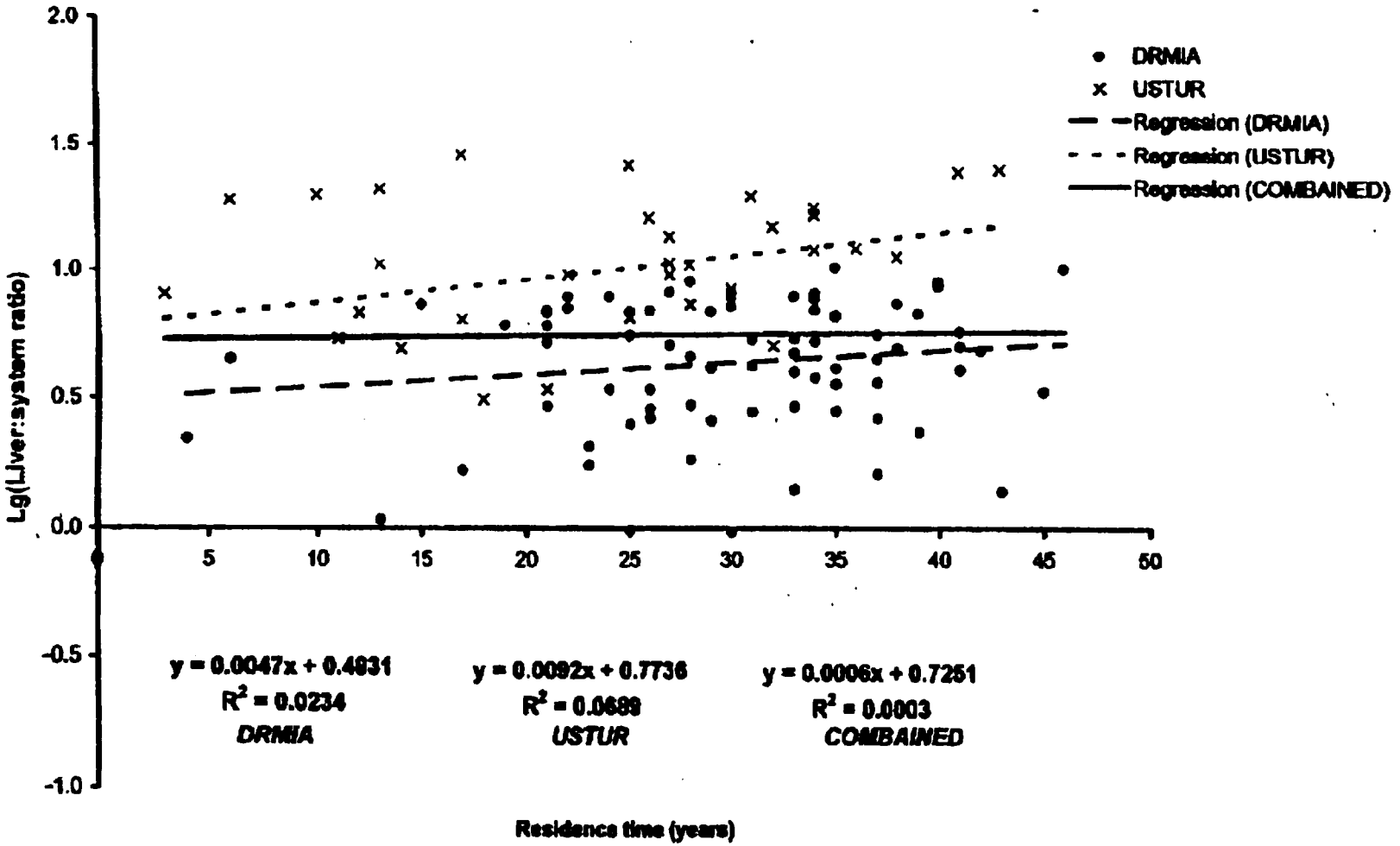

Figure G-3. Liver: System plutonium concentration ratios as a function of residence time for people with serious diseases of liver (patology group 3)

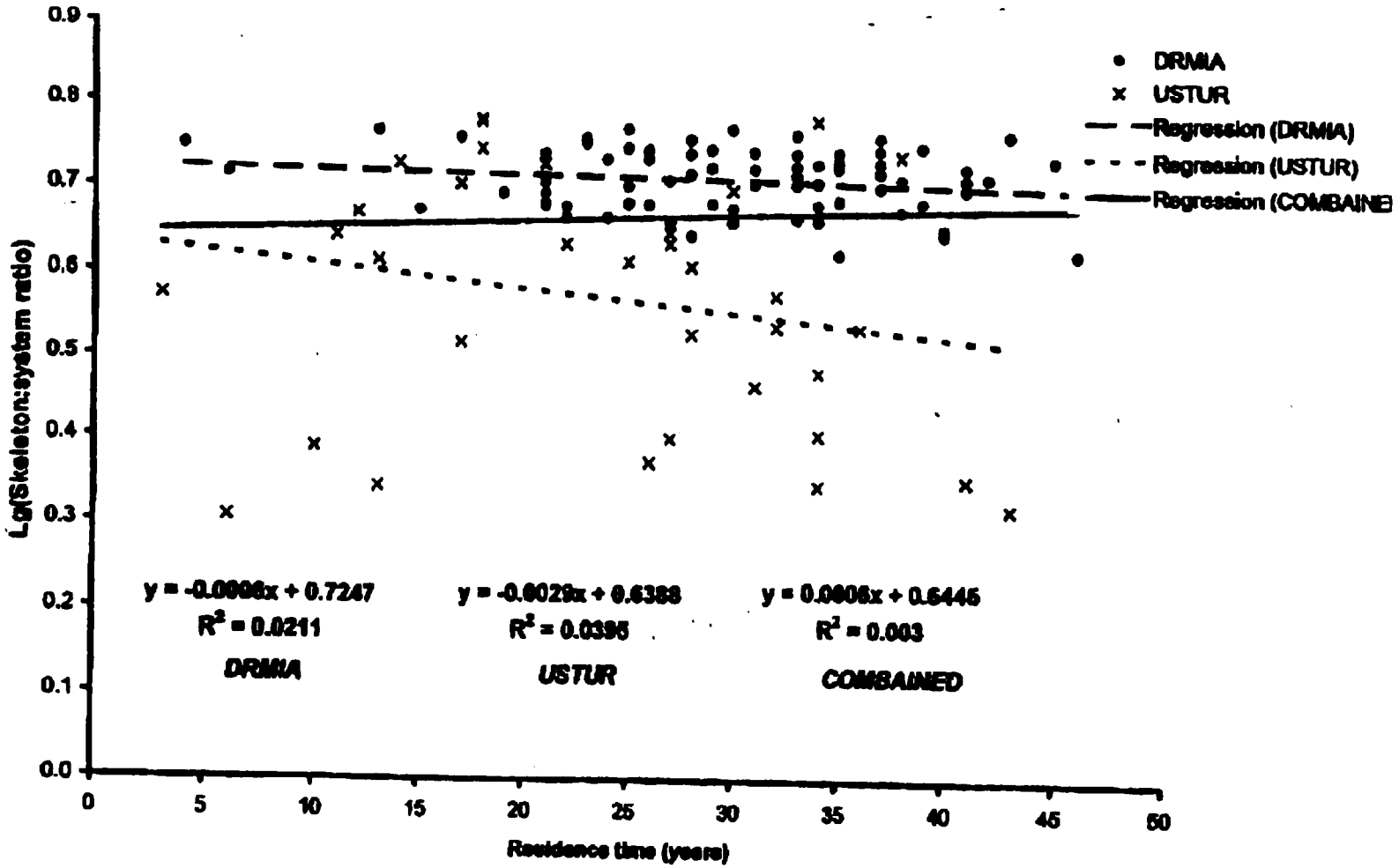

Figure G-4. Skeleton: System plutonium concentration ratios as a function of residence time for people with serious diseases of liver (patology group 3)

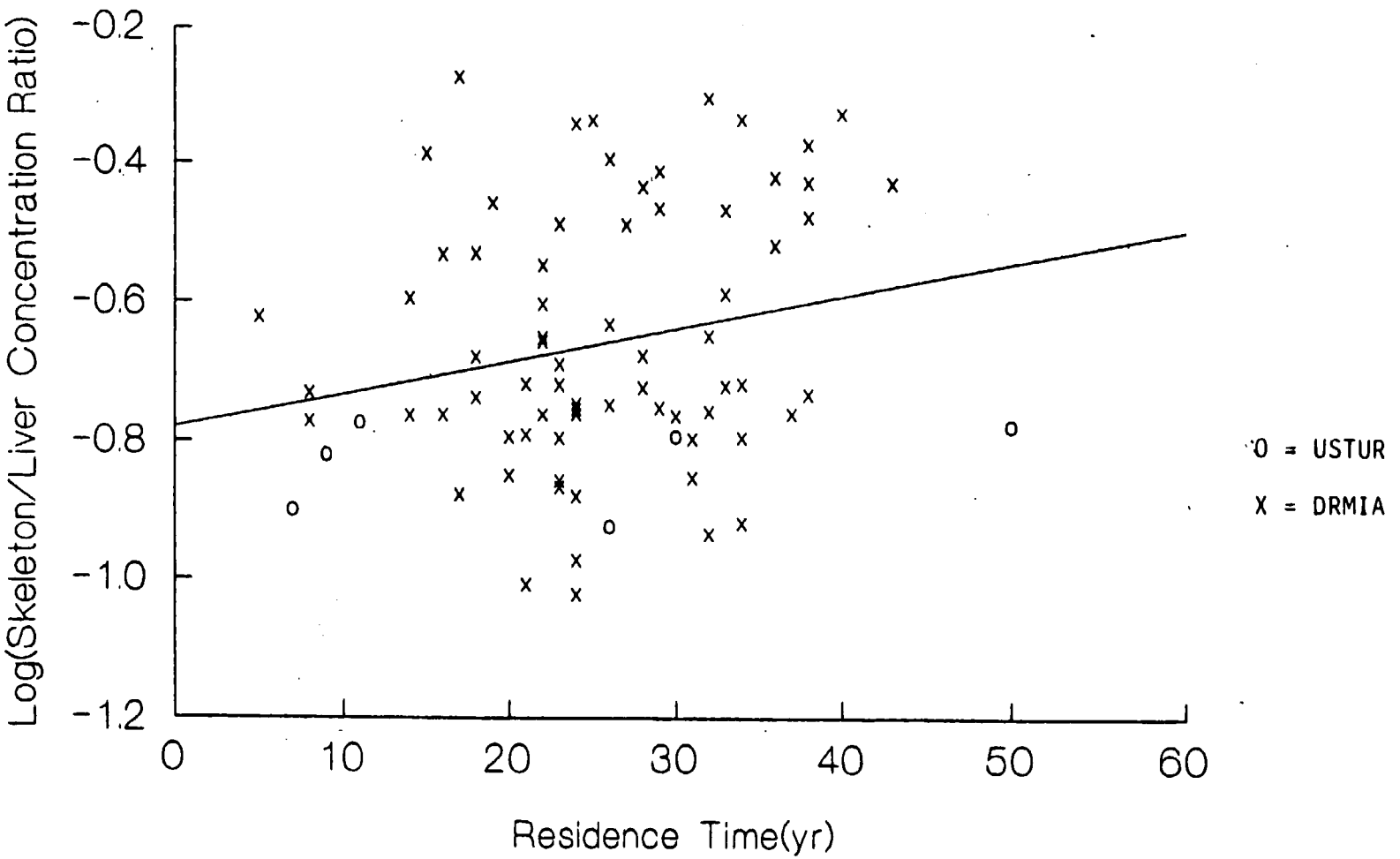

Figure G-5. Skeleton: liver plutonium concentration ratios as a function of residence time in a group of relatively healthy individuals (health group 1)

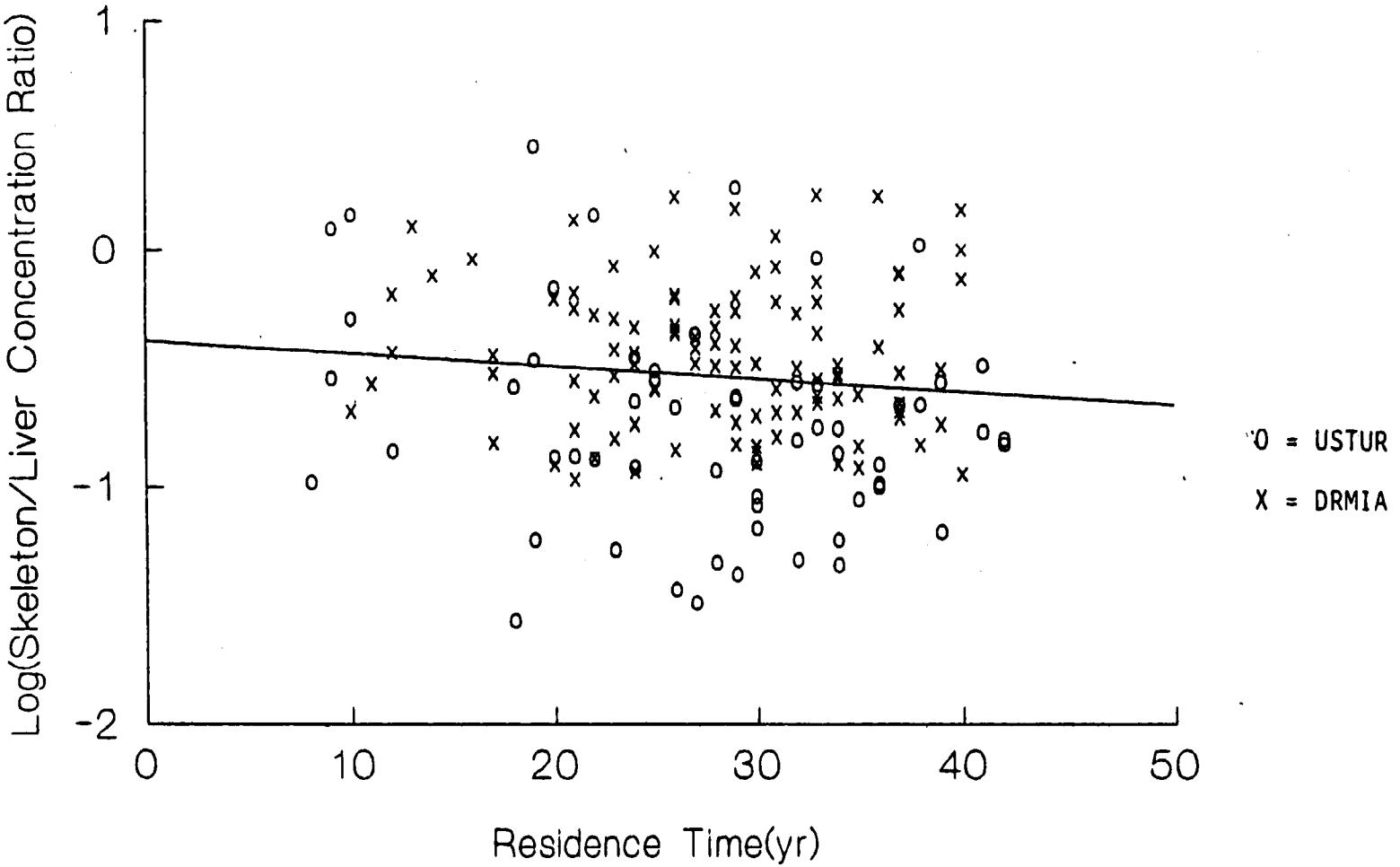

Figure G-6. Skeleton: liver plutonium concentration ratios as a function of residence time in a group of individuals with severe disease conditions not involving the liver (health group 2)

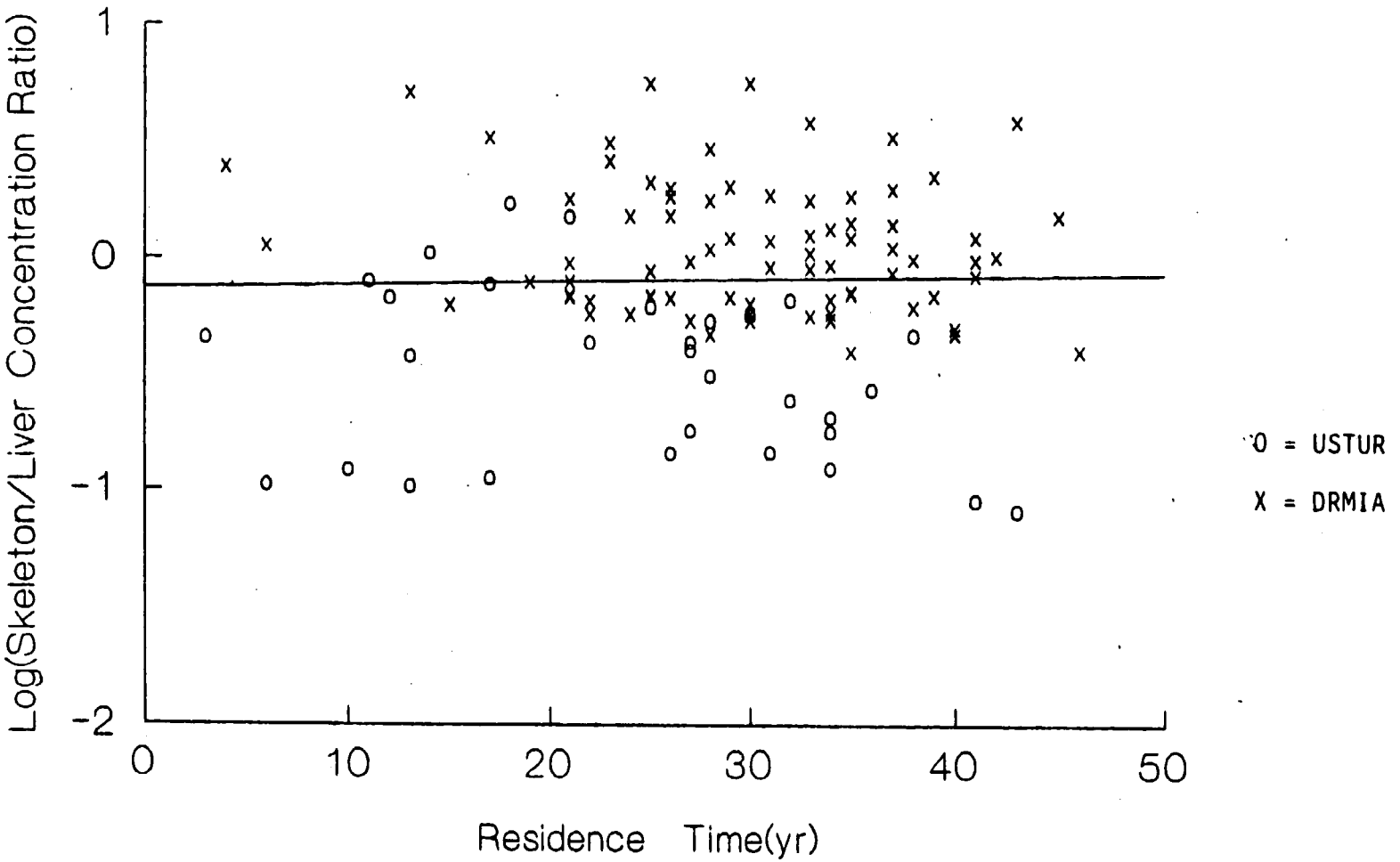

Figure G-7. Skeleton: liver plutonium concentration ratios as a function of residence time in a group of individuals with severe liver disease (Health group 3)

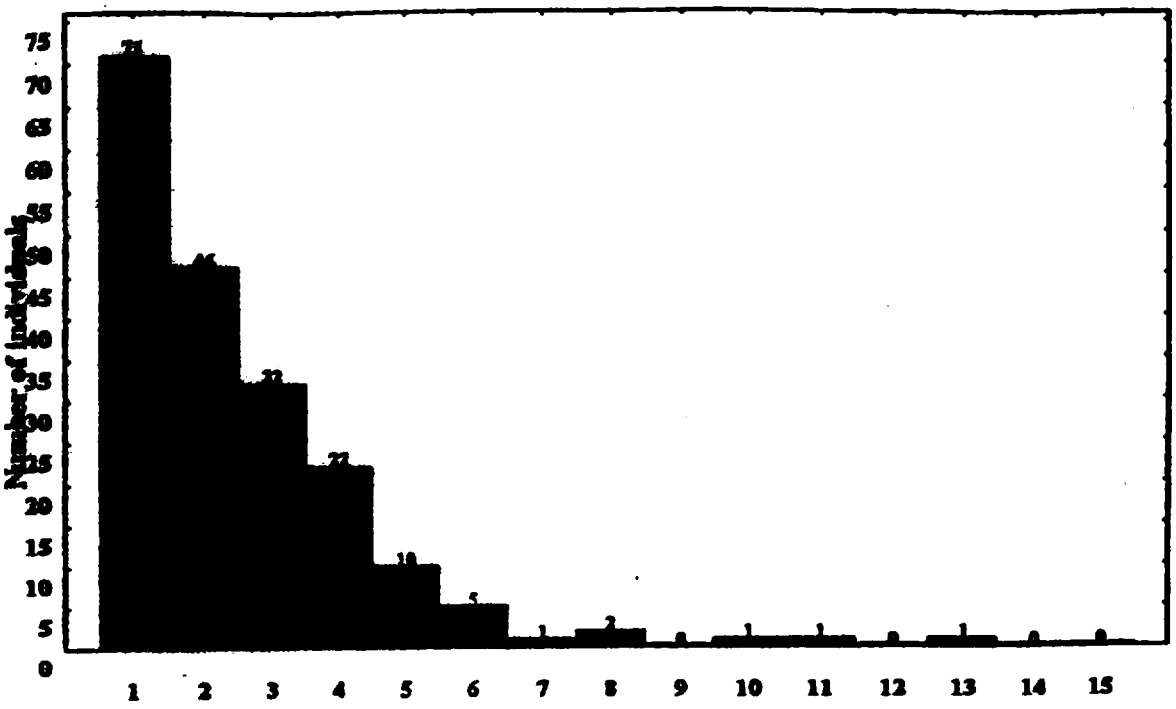

Figure H-1. Distribution of the number of bioassays per individual

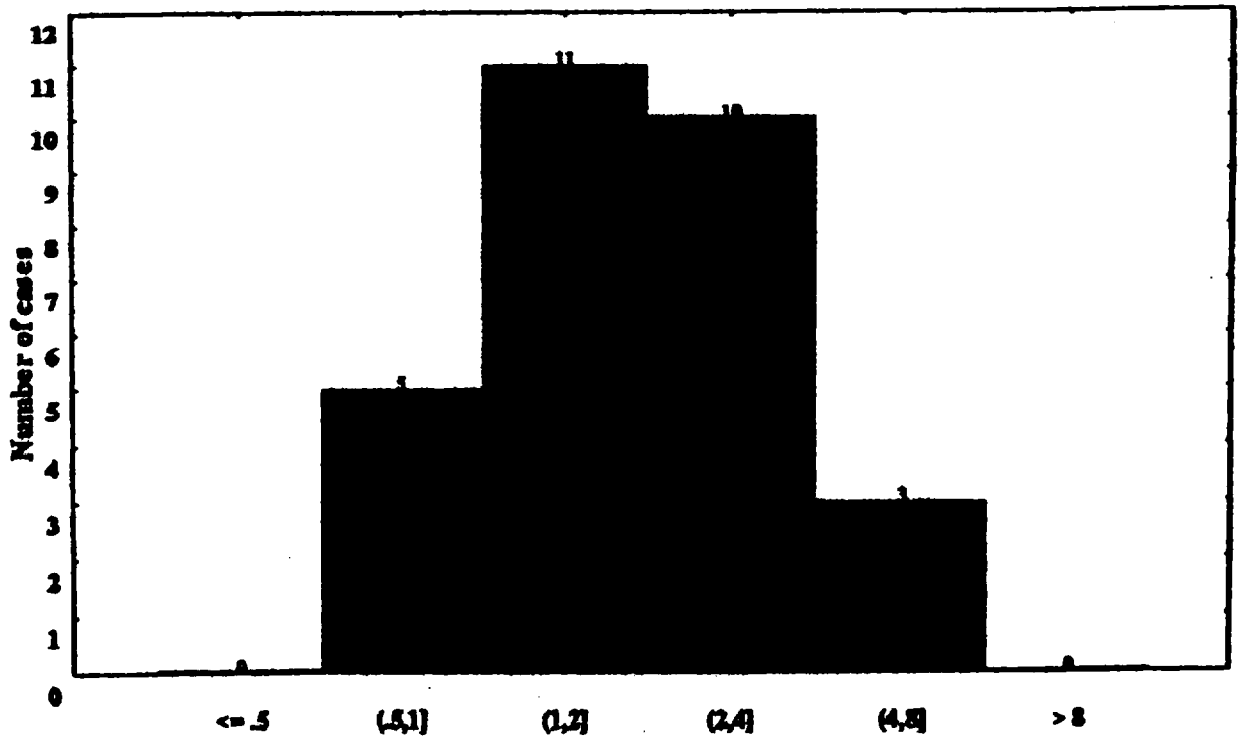

Figure H-2. Distribution of plutonium urine excretion factor, K_s in relatively healthy Individuals (health group 1)

Analysis For Actinides In Tissue Samples From Plutonium Workers Of Two Countries

R. E. Filipy, V. F. Khokhryakov, K. G. Suslova, S. A. Romanov, D. B. Stuit, E. E. Aladova, R. L. Kathren

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Analysis for actinides in tissue samples from plutonium workers of two countries

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For more than 25 years, the United States Transuranium and Uranium Registries (USTUR) and the Dosimetry Registry of the Mayak Industrial Association (DRMIA) of the Russian Federation have, each independently, collected tissues at autopsy from workers with potential or confirmed body burdens of actinide elements resulting from occupational exposures. Tissues, thus obtained, were radiochemically analyzed for actinides for the purpose of evaluating the biokinetics of these elements in the human body. Scientists of these two organizations have recently begun a collaborative research program to compare, combine and analyze the data to verify or refine biokinetic models needed for radiation dosimetry.

Introduction

The United States Transuranium and Uranium Registries (USTUR) collects tissue samples at autopsy of volunteer donors who have had a demonstrated occupational intake of one or more of the actinide elements. The program was begun in 1968 and, since then, tissues have been collected from nearly 300 autopsies and from 12 whole-body donors. The collected tissues were radiochemically analyzed to determine the actinide contents at death and this information is used to evaluate the deposition and retention of those elements in the body and to compare the organ contents with estimates of the body burdens made during the life of the individual donor. The primary objective of the USTUR is to ensure the adequacy of radiation protection standards and to verify or suggest modification of the models used as a basis for those standards for the actinide elements.[1,2]

The Dosimetry Registry of the Mayak Industrial Association (DRMIA), operated by Branch No. 1 of the Russian Institute of Biophysics, has been in existence for nearly the same period of time with similar operating procedures and with the same primary objective. Both Registries have operated independently of one another until 1994 when an international agreement for a collaborative research program was consummated between the governments of the Russian Federation and the United States. There are a number of differences in the methods and scopes of operation of the two Registries as well as many similarities. The purpose of this report is to briefly describe some of these similarities and differences which were addressed, in detail, in another report[3] and to provide a summary of the collaborative research program currently being conducted by the USTUR and the DRMIA.

One of the major differences between the two Registries is in the scope of operation. The workers of Mayak plutonium production facility are the primary concern of the DRMIA who perform the internal dose assessment for the workers of that site. This includes urine bioassays for actinides as well as the in-vivo screening (whole body counting) of Mayak workers. The DRMIA database contains dosimetry and medical records on approximately 5500 workers at the Mayak site. The USTUR, on the other hand, has volunteer donors from nearly all U. S. nuclear production sites and, with a few exceptions, performs no urine bioassays or in-vivo detection assays for actinides. They rely on dosimetry and medical records provided by the employers of their worker-registrants.

Table 1 contains information about the numbers of deceased cases and associated actinide body burdens for which data are maintained in the databases of the two Registries. The DRMIA has performed autopsies on approximately three times the number of cases of the USTUR although, not reflected in the table, the USTUR has had 12 whole body donors and the DRMIA has had none. Results of the radiochemical tissue analyses and the case descriptions and evaluations for six of these cases have been documented in several USTUR publications. The whole body donations have been extremely valuable in relating the actinide contents of the various tissues or organs of the body to one another and the data from them have been used by both Registries for that purpose. The actinide body burdens of DRMIA cases were also much higher than those of the USTUR cases. In a direct comparison, the mean liver concentration of DRMIA cases was nearly 250 times that of USTUR cases.[3]

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Table 1. A comparison of the USTUR and DRMIA databases

Registry	Nuclide	Program started	Total number of autopsies	Range of body burdens
DRMIA	$^{239+240}Pu$	1965	870	40 Bq–175 kBq
	^{241}Am	1975	460	2.0 Bq–4.5 kBq
USTUR	$^{239+240}Pu$	1968	280	40–300 Bq*
	^{241}Am	1968	280	1.0–150 Bq*

* A general range with a few lower and a few higher burdens.

Experimental

Radiochemical analysis

A major difference in the operation of the two Registries lies in the specific radiochemical methods used to analyze previously collected tissue samples. The USTUR has had radioanalytical support from four laboratories from the time of its inception as the National Plutonium Registry in 1968. An analytical laboratory at the Rocky Flats Facility (RF) analyzed tissues donated by those individuals who had been employed at that site. Pacific Northwest Laboratories (PNL) analyzed tissues of all other donors. In 1978, a laboratory at Los Alamos National Laboratory (LANL) also began analyzing tissues for the Registries and for several years, all three laboratories served the Registries. PNL analyzed tissues from approximately 30 cases before their analyses stopped in 1978. RF analyzed tissues from 60 cases before 1987 when their analytical function ceased. LANL analyzed tissues from over 100 cases including 6 whole-body donations before the Washington State University (WSU) laboratory took over the analytical function in 1993. Data from the analysis of tissues from approximately 50 cases were provided to the USTUR by laboratories in Great Britain. Tissues of all the DRMIA cases have been analyzed by the same methods throughout its history and its methods were quite differenct from those of the USTUR laboratories whose methods differed somewhat over the years.

The DRMIA methods as well as those of all USTUR laboratories began with variations of ashing techniques (wet or dry ashing) and subsequent dissolution of the ashed material in nitric acid. PNL used lanthanum fluoride co-precipitation followed by extraction of plutonium with thenoyltrifluoroacetone (TTA) while RF, LANL, WSU, and the DRMIA laboratories used anion-exchange chromotography to extract the actinides from the acid solution. DRMIA used diethyl-hexyl phosphoric acid (HDEHP) in toluene to separate americium from plutonium while RF, LANL, and WSU used dibutyl-N, N-diethylcarbamyl phosphonate (DDCP) for that purpose. The American laboratories other than PNL used isotopic tracers to quantitate recoveries from the solutions; the DRMIA use of tracers was intermittant because of difficulty in obtaining tracers of sufficient purity. For detection of the actinides in samples, PNL used two different methods, both of which were performed on the actinides after electrodeposition on stainless steel disks. An autoradiographic technique[4] was used for low-level samples while direct, electronic counting of alpha particles was used for samples containing a sufficient amount of activity. RF, LANL, and WSU used electrodeposition on stainless steel disks and solid-state alpha detectors. The DRMIA used bismuth phosphate co-precipitation and a Zinc sulfide scintillation method[5] for their higher level samples and, for low-level samples they used the bismuth phosphate co-precipitation, followed by electrodepositon and an ion chamber spectrometer. The WSU laboratories followed the procedures developed at LANL[6] for the sake of continuity because LANL analyzed the greatest number of USTUR tissue samples. New, more efficient methods are being investigated by WSU and those methods, after appropriate verification, will likely be used with future samples of WSU and the DRMIA.

Results and discussion

Data comparison

In spite of the differences in radiochemical analytical methods used by the two Registries over the years and regardless of the large difference in actinide body burdens between the two Registries, the resultant data are similar in many respects. In the inital stages of collaboration by the USTUR and the DRMIA, data were compared to determine whether or not they could be combined to evaluate biokinetic models. The first comparison of data involved the use of skeleton-to-liver concentration ratios. The skeleton and the liver are the two major deposition sites in human (or animal) bodies. Ratios were used because they were not expected to differ substantially with high or low body burdens and because estimates of initial depositions and the times of exposure in human subjects are frequently misleading, precluding the use of retention functions for individual organs that are based on initial uptake.

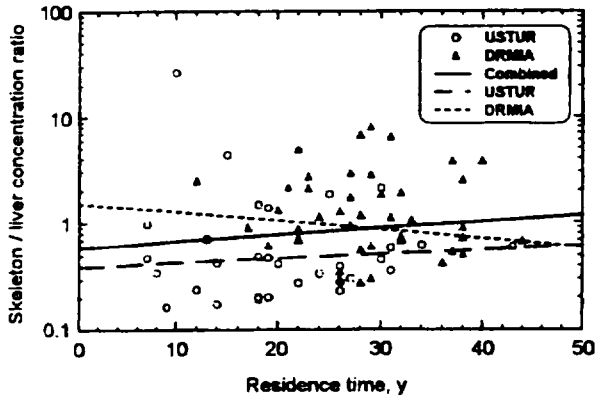

Fig. 1. Skeleton-to-liver ^{241}Am concentration ratios as a function of residence time (time between exposure and death) in workers occupationally exposed to actinide elements

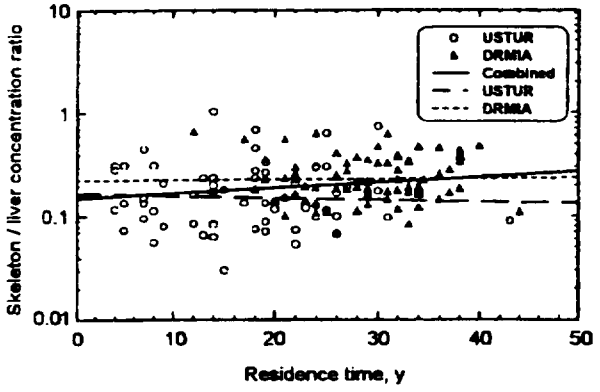

Fig. 2. Skeleton-to-liver ^{239}Pu concentration ratios as a function of residence time (time between exposure and death) in workers occupationally exposed to actinide elements

Table 2. Selected parameters describing the skeleton:liver concentration ratios for plutonium and americium in the bodies of workers of the United States and the Russian Federation

	USTUR	DRMIA	Combined data
$^{239+240}Pu$			
No. of cases	66	74	137
Geometric mean[a]	−0.81	−0.64	−0.71
GSD[b]	0.37	0.22	0.27
Slope[c]	−0.0020	0.0010	0.0060
P[d]	0.77	0.92	0.028
^{241}Am			
No. of cases	30	42	74
Geometric mean	−0.32	0.62	−0.064
GSD	0.35	0.36	0.45
Slope	0.0040	−0.0040	0.015
P	0.59	0.63	0.29

[a] Mean of the logarithms of skeleton:liver concentration ratios.
[b] Geometric standard deviation of the concentration ratios.
[c] Slope of the regression lines relating the logarithms of concentration ratios to residence times (time between exposure and death).
[d] Probability that the slope of the regression line was not significantly different from zero ($P < 0.05$).

Figure 1 is a plot of skeleton:liver concentration ratios of $^{239+240}Pu$ as a function of residence times (the time between exposure or potential exposure and death) and Table 2 contains selected parameters describing those plots. Although the concentration ratios ranged over two orders of magnitude, geometric mean ratios of the two Registries (Table 2) were not significantly different from one another ($P < 0.05$). The ratios of each Registry as well as those of the combined data were log-normally distributed. Slopes of the individual regression lines for the data of each Registry (Fig. 1) were not significantly different from one another and were not significantly different from zero ($p < 0.05$); however the slope of the regression line for the combined data was significantly different from zero ($p = 0.03$). Means of ^{241}Am skeleton:liver concentration ratios or the two Registries (Table 2) were also not significantly different from one another ($P < 0.05$). Slopes of the ratio vs residence time regression lines (Fig. 2) were also not significantly different from one another and the slopes, including that of the regression of combined data, were not significantly different from zero ($P < 0.05$).

The main difference between the data points of the two Registries was in the residence time parameter. Residence times of the DRMIA cases were generally longer than those of the USTUR cases (Figs 1 and 2) because of the method of calculation. USTUR residence times were the time period between exposure (or potential exposure) and death of the worker and, if no exposure situation was evident, the time period including 67 percent of the worker's time working in a potential exposure situation plus the time between cessation of work and death.[7] The DRMIA includes the entire period of occupational exposure to plutonium plus the time between cessation of work and death in their residence times. This difference would not be likely to have an appreciable effect on the regressions in Figs 1 and 2; however, the data will be reviewed in the interest of uniformity before they are used in biokinetic models.

Future collaborative research

A three-year collaborative research project was proposed by the DRMIA and the USTUR and was approved for funding by the U. S. Department of Energy Office of International Health Studies. Twelve major tasks were proposed and the following is a summary of those tasks.

The first task involves intercomparisons of radiochemical analytical methods currently in use by both Registries including a series of performance evaluations with split samples from both laboratories and, ultimately, with standard reference materials prepared by the U. S. National Institute of Standards and Technology. Information thus gained will be used to

identify and adjust for consistant differences that might be present in previously collected data of the two Registries before they are combined. Other tasks include establishment of uniform analytical methods to be used by both laboratories for future analyses with respect to sampling methods, ashing methods, actinide separation techniques, spectroscopy methods, and data recording.

Methods used by the two Registries for in-vivo estimates of actinide body burdens will also be compared with the goals of joint analysis of previously collected data and establishment of uniform methods for future collection of data. This task includes calibration of the in-vivo detection equipment used by the DRMIA against that in use in the United States by the exchange of whole-body phantoms. Urinalysis for actinide elements is a tool that has been used by the DRMIA and by the employers of USTUR Registrants to estimate intakes of those elements. The radioanalytical methods used for those estimates will be compared to determine compatibility of the data collected by both Registries.

Radiation dosimetry from plutonium and americium has been a primary goal of both Registries since their inceptions. A number of tasks will be performed in which biokinetics of these elements in occupationally-exposed humans will be examined with DRMIA and USTUR data. Tasks include evaluation of the relationships of actinide concentrations in the lungs, thoracic lymph nodes, and the individual systemic organs at the time of death and comparison of those data with the estimates of body burdens made while the individuals were alive. The purpose of this work is to verify or suggest modifications of models describing the translocation of actinides in the body as proposed by the International Commission on Radiological Protection.[8,9]

There are a number of advantages to be gained by collaboration of the two Registries. Collaboration would increase the number of cases available for study by a factor of four for already deceased registrants relative to the number of USTUR cases. Also, there were many more female plutonium workers in Russia than in the United States. The USTUR database contains data from only a few females; therefore, combination of data would result in a greater heterogeneity of the worker population. Because actinide deposition levels in past Russian workers were much higher than those of U. S. workers, dose-dependence or dose-independence of biokinetic parameters should become apparent with the combined databases.

An important part of this work includes the dissemination of information to the world scientific community and the general public. This will be accomplished by prompt, joint publication of the results of the collaborative research in the scientific literature. Also as part of this collaboration, a number of important Russian documents regarding plutonium metabolism and dosimetry, previously classified, will be translated to English and distributed through the scientific literature.

The dosimetric information resulting from this project will be in direct support to other projects which are a part of the overall program. The objectives of two other, separate projects are to relate internal doses combined with external doses to stochastic effects, such as cancer, and to deterministic effects, such as blood dyscrasia, noted in workers at the Mayak plutonium production site. Still other projects of the joint U. S.-Russian program are concerned with dosimetry as well as stochastic and deterministic effects in the general Russian population residing in the vicinity of the Mayak site and the results of this worker dosimetry project are expected to be helpful in the dose reconstruction efforts for that population. The biokinetic data and organ doses, in conjunction with biological effects, will be used to develop and define risk coefficients for those effects resulting from chronic exposure to relatively high levels of radiation.

*

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References

1. R. L. KATHREN, Radiat. Protect. Dosimetry, 26 (1989) 323.
2. R. L. KATHREN, Radiat. Protect. Dosimetry, 53 (1994) 1.
3. K. G. SUSLOVA, R. E. FILIPY, V. F. KHOKHRYAKOV, S. A. ROMANOV, R. L. KATHREN, Radiat. Protect. Dosimetry, 67 (1996) 13.
4. L. C. SCHWENDIMEN, J. W. HEALY, Nucleonics, 16 (1958) 78.
5. V. F. KHOKHRYAKOV, T. I. KUDRYAVTZEVA, V. I. CHERNIKOV, I. A. ORLOVA, J. Radioanal. Chem., 234 (1998) 293.
6. J. F. MCINROY, H. A. BOYD, B. C. EUTSLER, D. ROMERO, Health Phys., 49 (1985) 587.
7. R. E. FILIPY, R. L. KATHREN, Health Phys., 70 (1996) 153.
8. International Commission on Radiological Protection, Human Respiratory Tract Model for Radiological Protection, Publication 66, Pergamon Press, Oxford, Ann ICRP 24(3/4) 1994.
9. International Commission on Radiological Protection, Age-dependent Doses to Members of the Public from Intake of Radionuclides, Part 2, Publication 67, Pergamon Press, Oxford, Ann. ICRP 23(3/4), 1993.

Classification Of Alpha-active Workplace Aerosols Based On Coefficient Of Transportability As Measured By The Dialysis Method

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Classification of alpha-active workplace aerosols based on coefficient of transportability as measured by the dialysis method

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This report describes a method by which potentially inhaled workplace aerosols containing plutonium compounds are classified on the basis of measured transportability in Ringer's solution. It is suggested that the criterion "transportability" be used in the ICRP respiratory tract model. Transportability is measured as the fraction of plutonium alpha activity, deposited on a collecting filter, that passes through a semi-permeable membrane in Ringer's physiological solution during two days of dialysis. First order kinetic equations are used for explanation of dialysis results. The dissolution characteristics of alpha-active aerosols are important in interpretation of their passage from the lungs after inhalation.

Introduction

The retention and clearance of inhaled plutonium containing aerosols deposited in a worker's lungs are determined, in part, by the particle size distribution and their solubility.[1,2] Experimental studies with animals[3,4] and available information on pulmonary deposition in workers after accidental inhalation exposures[5,6] show that the lung clearance of plutonium particles varies widely depending on the chemical form of inhaled compounds. The chemical properties of actinides, in particular of plutonium, have been studied in detail; however, the data about their solubility in the classic chemical sense are not useful for predicting their behavior in the body.

Due to the absence of a strict correlation between metabolic parameters and chemical forms of radionuclide compounds, the ICRP dosimetry models of the respiratory tract group radioactive aerosols into three classes, D, W, or Y, i.e., those with rapid, moderate and slow removal from the respiratory tract.[1,2] Because of the lack of data describing the correlation between lung clearance rates and physico-chemical properties of inhaled aerosols, the indicated classification has a qualitative character. Also, workplace aerosols generally contain not one, but a mixture of several chemical compounds. And, last, the rate of lung clearance and the capacity to pass through the semi-permeable membranes in the body are influenced by particle size.

A number of investigators have studied aerosol characteristics which could allow prediction of biological behavior of inhaled radionuclides in man.[7–10] However, the literature data does not reveal criteria for characterization of workplace aerosols that can be used for practical dosimetry assessments. We have performed a detailed study of the dissolution characteristics of plutonium aerosols sampled at plutonium-handling facilities of the Mayak Industrial Association.

This report contains a description of a dialysis method for classification of workplace plutonium-containing aerosols on the basis of in vitro solubility for worker dosimetry assessments.

Experimental

Aerosol samples for dissolution studies were collected by standard aspiration methods on AFA-RSP-20 filters (Russian manufactured) from different workplaces of uranium and plutonium reprocessing plants. In the laboratory, each filter was sandwiched between two membrane filters (type Vladipor with pore size 0.15–0.25 μm) and mounted in a specially made holder. This assembly (Fig. 1) was placed in a 300-ml glass beaker with a 150-ml volume of Ringer's physiological solution (Table 1) at room temperature without stirring. At intervals of 1, 3, 7, 15, and 24 h after the beginning and at 24-h intervals thereafter, the solvent was removed and replaced with a fresh solution and the plutonium activity was determined in the removed solution. At the end of 14 d, the plutonium remaining on the filter was assayed and that activity value was added to those of the solutions to determine the amount of plutonium initially present on the filter. Samples were analyzed using methods described in a previous report.[12] The dissolution rate was expressed as the percent of plutonium dissolved from the total initial content per unit time.

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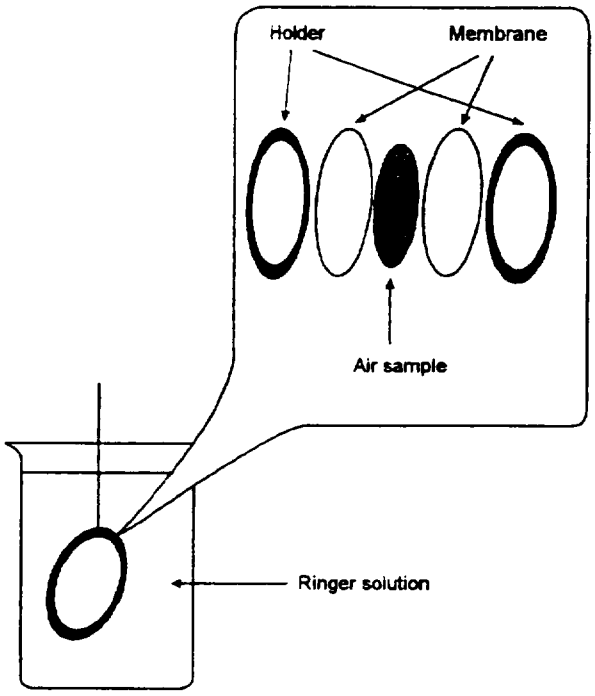

Fig. 1. Assembly of the components for the dialysis method

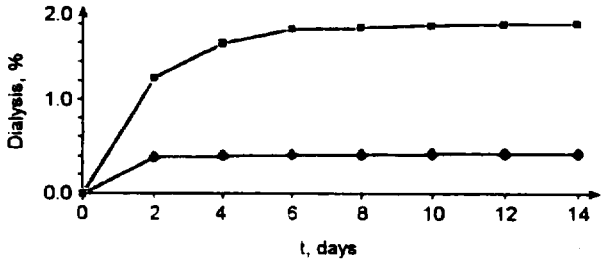

Fig. 2. The cumulative percentage of plutonium dialysis from aerosols sampled at two different workplaces of the radiochemical plant

Table 1. The composition of Ringer's physiological solution[11]

Salt	Concentration, $g \cdot l^{-1}$
NaCl	8.5
Kcl	0.2
$CaCl_2$	0.2
$NaHCO_3$	0.1

Results

In order to evaluate the dialysis method for the purpose of dosimetry classification, the dialysis of plutonium citrate and plutonium polymeric nitrate was studied. The dissolution rate of plutonium citrate was much higher than that for polymeric plutonium with 84.7 ±9.7% of the initial amount of plutonium citrate dissolved after two days of dialysis. With the less soluble polymeric plutonium nitrate, only 4.4±1.7% of the plutonium was in solution after two days. Plutonium citrate is a highly stable complex that is referred to monomeric plutonium; it has a high capacity for diffusion through a semi-permeable membrane during the dialysis. The low dissolution rate of polymeric plutonium can be explained by the larger particle size relative to the membrane pore size of 0.25 μm. Another reason for slow dialysis of polymeric plutonium may be adsorption on the membrane. Appreciable differences in the dialysis of the two plutonium compounds were recorded and a good correlation between the dialysis rate and compound chemical form was noted.

The composition of workplace aerosols may be very complex. As a rule, these materials contain a mixture of plutonium compounds of varied chemical forms depending on the technological process in the workplace where the aerosols were generated. Therefore, during dialysis of workplace aerosols in the Ringer's solution, many different interactions can occur.

Analysis of dialysis kinetics of a large number of plutonium-containing aerosols revealed biphasic rate profiles. In all cases, there was fast dissolution in the earlier stage which could last from several hours to one day, depending on the workplace from which the aerosols were sampled. After 2 days, the dissolution rate of plutonium was reduced by two or more orders of magnitude relative to the value obtained for the first several hours and then the rate became nearly constant. The results of these studies are demonstrated by dialysis of typical plutonium aerosols sampled from two different plutonium-processing areas (Fig. 2).

The presence of two phases, as a first approach, can be described by a system of first order equations as follows:

$$dQ_1/dt = -\lambda_1 Q_1 + \lambda_2 Q_2 \quad (1)$$

$$dQ_2/dt = -\lambda_2 Q_2 \quad (2)$$

where: Q_1 is the fraction of rapidly dissolving radionuclide at time, t, Q_2 is the fraction of slowly dissolving radionuclide at time, t, λ_1 is the constant corresponding to the dissolution rate of the rapidly diffusing, soluble fraction into the external solution, and λ_2 is the constant corresponding to the slow dissolution rate of large particles breaking down.

The first equation describes the removal of the soluble component from the sample by rapid diffusion of small particles into the external solution and Eq. (2) describes replenishment as a result of transformation of large particles.

Table 2. Transportability (S) and the fraction of plutonium alpha activity dialysing in two days (D) of industrial aerosol samples from different radiochemical production workplaces

Technological process step	Dialysis parameters a, %	λ, day^{-1}	S, %	D, %	D/S
Reprocessing of uranium fuel (workplace 1)	$a_1 = 2.7$ $a_2 = 97.3$	$\lambda_1 = 1.0$ $\lambda_2 = 0.0023$	2.92	2.80	0.96
Reprocessing of uranium fuel (workplace 2)	$a_1 = 2.4$ $a_2 = 97.6$	$\lambda_1 = 2.1$ $\lambda_2 = 0.0021$	2.50	2.30	0.92
Plutonium fuel production (workplace 1)	$a_1 = 0.84$ $a_2 = 99.16$	$\lambda_1 = 1.10$ $\lambda_2 = 0.00077$	0.90	0.80	0.89
Plutonium fuel production (workplace 2)	$a_1 = 0.12$ $a_2 = 99.88$	$\lambda_1 = 0.92$ $\lambda_2 = 0.00025$	0.15	0.16	1.07

Mean ± standard deviation: 0.97±0.07

Table 3. The relationships between transportability, S, of industrial aerosols and the percentage of postmortem plutonium body burdens remaining in the respiratory tract

Workplace	Reprocessing of uranium fuel	Plutonium fuel production (workplace 1)	Plutonium fuel production (workplace 2)
Transportability, S, %	3.21±1.69	1.0±3.0	0.20±1.55
Number of cases	281	112	45
Lung content,* %	2.56±2.26	6.50±2.47	22.6±1.81
Lung and lymph node content,* %	3.60±2.30	13.2±2.47	43.2±1.80

* Percent of total body burden; geometric mean ± geometric standard deviation.

Let us assume that Q_0 is the initial content of plutonium alpha-activity on the sample filter, S is the transferable portion of radionuclide at the initial moment (the untransferable portion is accordingly 1-S), thus we can write equations describing the initial conditions:

$$Q_1 \Big|_{t=0} = S \times Q_0 \tag{3}$$

$$Q_2 \Big|_{t=0} = (1-S) \times Q_0 \tag{4}$$

The solution of Eqs (1) and (2) under initial conditions gives the following expression for initial plutonium content in the sample:

$$Q = Q_1 + Q_2 = Q_0 [a_1 \exp(-\lambda_1 t) + a_2 \exp(-\lambda_2 t)] \tag{5}$$

$$a_1 = S - (1-S)\,\lambda_2/(\lambda_1 - \lambda_2) \tag{6}$$

$$a_2 = (1-S)\,\lambda_1/(\lambda_1 - \lambda_2) \tag{7}$$

$$S = a_1 + a_2 \lambda_2/\lambda_1 \tag{8}$$

Thus Eq. (8) can be applied to dialysis results to calculate the value, S, the transportable fraction (S is defined as Transportability). Clearly such an approach to the process kinetics is an over simplification because polydisperse aerosols, in the early stages of dialysis, cannot be described by one term exponentially decreasing with time. To solve Eq. (8), it is necessary to know all parameters of the two-component exponential model. These parameters can be obtained only by continuing dialysis for a week or longer which is not practical. It is possible to simplify the determination of S by obtaining, D, an approximate value of S resulting from two days of dialysis. Analysis of dialysis data from a large number of air samples selected from different radiochemical production workplaces show that the alpha activity dialyzed over the first two days, D, closely corresponds to transportability, S, calculated from the data of prolonged dialysis.

This simplified approach to assessement of transportability is illustrated by the dialysis results from aerosols sampled at different workplaces at the Mayak

radiochemical plants. Mean values of the dialysis kinetic parameters obtained from many trials are given in Table 2. Transportability, S, was calculated with Eq. (8). Table 2 also contains dialysis data for the first two days, D. The data of Table 2 show that the alpha-activity fraction dialysing in two days, D, coincides with the calculated value for transportability, S. These values range over more than one order of magnitude for aerosol samples from different workplaces.

Discussion

The salt composition of Ringer's solution is similar to that of tissue fluids. Dialysis through semi-permeable membranes involving dissolution and diffusion is similar to some mechanisms of lung clearance. It is reasonable to apply the dialysis method to characterization of plutonium aerosols for dosimetry assessment purposes. Our classification results are in good agreement with the ICRP respiratory tract model.[1,2] The dialysis method appears to be a good method for classification of workplace aerosols to predict their clearance times from the respiratory tract.

The clearance time of aerosol particles from the lungs is inversely related to the fraction absorbed into the blood. Plutonium oxide aerosols, according to the dialysis method, are in inhalation class Y with prolonged retention in the alveolar region and mimimal absorption into the blood from the nasal and bronchial regions. Plutonium nitrate and chloride aerosols are in a class with moderate retention in the pulmonary region and moderate absorption from extrathoracic regions. The dialysis data from plutonium citrate and plutonium polymeric nitrate (reported above) and from aerosol samples collected in different workplaces (Table 2) indicate that the transportability value, S, essentially varies with solubility properties of plutonium compounds. Data in Table 2 shows that the value, S, for aerosols of workplace 2 in the plutonium reprocessing plant (where the plutonium dioxide is the main concern) is more than one order of magnitude lower than that for aerosols at workplaces of the uranium reprocessing plant (where the mixtures of moderately soluble plutonuium compounds such as nitrate, chloride, and oxalate are present). According to the ICRP lung model for the indicated plutonium compounds, the absorption fractions in the respiratory tract vary within approximately the same ranges.

By means of the dialysis method, it is possible to characterize aerosols with respect to their predicted transfer processes in the lung. It is expected that the amount of plutonium in the lung as a fraction of the total amount retained in the body, long after inhalation, should be inversely related to transportability of the alpha-active aerosol. This assumption is confirmed by post-mortem lung distribution of plutonium in workers who were occupationally exposed to aerosols with different mean values of transportability at the production areas described above. The data from many years of autopsy research, given in Table 3, show that the relative nuclide content in lungs is inversely related to transportability.

Considering that plutonium taken into the body is subject to absorption from the respiratory tract, it is expected that the fraction of the total body content in the lung at death should be strongly dependent on the duration of exposure. Examination of the exposure histories of the workers whose data are shown in Table 3, shows that the duration of time from the beginning of work with plutonium until death was approximately the same and equal to 28–29 y in each workplace. On that basis, we can presume that the relative plutonium content in lungs of personnel working at the different industrial sites was correlated with the transportability properties of the inhaled aerosols rather than to exposure duration. Such a correlation leads to the conclusion that it is possible to establish a quantitative relationship between clearance parameters of the plutonium metabolic model from the respiratory tract and measured transportability. This approach can be especially useful in the case of workers exposed to mixed plutonium-containing aerosols when the classification by the ICRP lung model is not practical.[12]

*

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References

1. Annals of the ICRP, Publ. No. 30:Limits for intakes of Radionuclides by Workers, Pergamon Press, Oxford, 1978.
2. Annals of the ICRP, Publ. No. 66: Human Respiratory Tract Model for Radiological Protection Pergamon Press, Oxford, 1993.
3. H. SMITH, G. N. STRADLING, B. W. LOVELESS, G. J. HAM, Health Phys., 33 (1977) 539.
4. G. M. KANAPILLY, O. G. RAABE, C. H. GOH, R. A. CHIMENTI, Health Phys., 24 (1973) 497.
5. O. G. RAABE, G. M. KANAPILY, H. A. BOYD, Inhalation Toxicology Research Institute Annual Report 1972-1973, Albuquerque,1973.
6. A. N. EFIMOVA, A. M. VOROBYEV, Gigiena and Sanitariya, 1 (1977) 41.
7. V. D. VASHI, C. S. SURYANARAYANAN, P. KOTRAPPA, Health Phys., 39 (1980) 108.
8. J. J. MIGLIO, B. A. MUGGENBURG, A. L. BROOKS, Health Phys., 33 (1977) 449.
9. O. G. RAABE, S. V. TEAGUE, N. L. RICHARDSON, L. S. NELSON, Health Phys., 35 (1978) 663.
10. A. F. EIDSON, J. A. MEWHINNEY, Health Phys., 45 (1983) 1023.
11. B. I. ZBARSKIY, I. I. IVANOV, S. R. MORDASHEV, Biol. Chem., (1954) 619.
12. K. G. SUSLOVA, R. E. FILIPY, V. F. KHOKHRYAKOV, S. A. ROMANOV, R. L. KATHREN, Radiation Prot. Dosim., 67 (1996) 13.
13. V. F. KHOKHRYKOV, S. A. ROMANOV, K. G. SUSLOVA, Health Effects of Internally Deposited Radionuclides: Emphasis on Radium and Thorium, World Scientific, London (1995) 117.

A Scintillation Method For Determination Of Actinide Alpha-Activity In Samples

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A scintillation method for determination of actinide alpha-activity in samples

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This report describes an efficient, easy to use, and inexpensive method for detection of alpha-activity in biological samples, the alpha radiometer. The actinide elements are coprecipitated from acid-dissolved, ashed samples with bismuth phosphate and the precipitate is then mixed with ZnS(Ag) scintillation powder. The mixture is dried, in a thin layer, on the surface of a polystyrene cuvet and scintillations from the layer are detected with a photomultiplier tube. An optimal counting efficiency is obtained with a scintillation powder thickness between 25 and 40 mg·cm^{-2}.

Introduction

Alpha-spectrometry is generally used in radiobioassay and radioecology applications for determination of alpha-activity in samples. While this method has high sensitivity and high resolution, its application to large numbers of samples is time consuming and expensive. For routine analyses of samples with known isotopic composition, the determination of alpha-activities is simpler and less expensive with the alpha radiometer. The radiometer has been a useful tool at the First Branch of the Biophysics Institute (BIB-1) for measuring the total plutonium content in urine bioassay samples of occupationally exposed workers of the Mayak plutonium production facility. The device was developed and fabricated over a 20 year period at BIB-1 and it has been in use since 1974. It was certified by the General State Center for Measurement Standards, D. Mendeleev NPO VNIIM, Saint Petersburg, Russian Federation.[1] The purpose of this report is to describe the equipment, the preparation of the samples, and the performance characteristics of the alpha radiometer.

Experimental

Sample preparation

The radiochemical separation of actinides from the sample has been described in previous reports.[2,3] The actinides (plutonium and americium) are separated from the acid-dissolved, ashed urine sample by bismuth phosphate co-precipitation. A solution of bismuth nitrate and sodium dihydrogen orthophosphate (1:6 by volume) is added to the sample in 1M nitric acid. The actinide-bismuth phosphate precipitate is separated by centrifugation and mixed with ZnS(Ag) scintillation powder and the mixture is suspended in 96% ethanol. The suspension is transferred to a shallow, 25 mm-diameter polystyrene cuvet and dried at room temperature, forming a thin layer of ZnS(Ag)-precipitate on the surface of the cuvet. The cuvet is coupled, in a light-tight enclosure, with a Model ФЭу-35 photomultiplier (of Russian manufacture) which detects scintillations in the mixture and converts them to electrical impulses. The electrical impulses are processed by an analog converter which registers an event on a counter. The photomultiplier has a low level of dark current which makes the detector background essentially zero with no scintillation powder in the cuvet. The background count rate with non-radioactive scintillation powder in the cuvet is $0.0009 \pm 0.0003\ s^{-1}$. Up to 20 identical modules are operated simultaneously at the BIB-1 laboratories.

Results and discussion

Performance

Performance characteristics of the alpha radiometer are shown in Table 1. The quantity of scintillation powder is an important factor influencing the sensitivity of the method. To determine the optimum quantity of ZnS(Ag), standard radioactive solutions of plutonium in nitric acid were added to control urine at two activity levels, 0.83 and 2.7 Bq. The urine was processed through the bismuth phosphate coprecipitation and equal aliquots of the precipitate were mixed with varying amounts of scintillation powder. The mixtures were counted with the alpha radiometer and the results are shown in Fig. 1.

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Table 1. Metrological characteristics of the low-background alpha radiometer

• Range of measurement	0.0014–0.5 Bq
• Background level*	0.0009±0.0003 s^{-1}
• Detector efficiency	95±5%
• Minimum detectable activity (MDA)*	0.0014 Bq

* Calculated by the method of BOECKER et al.[4] with sample and background measurements of 720 min.

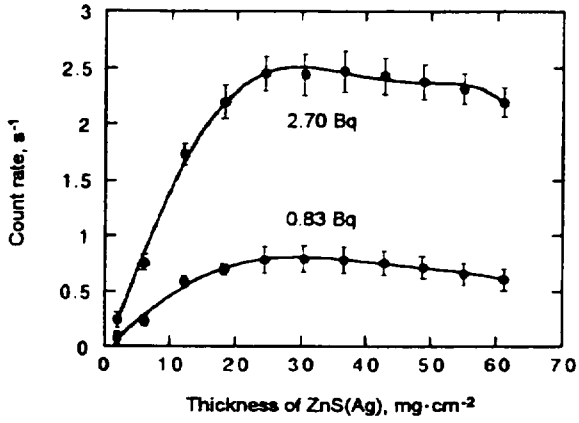

Fig. 1. Count rate measured by alpha radiometer with varying thickness of ZnS(Ag) scintillation powder in the cuvet. Error bars represent 1 σ measurement uncertainty

The results in Fig. 1 show that the highest counting efficiency was achieved when the thickness (mass/unit area of cuvet) of the scintillation powder and the precipitate was between 25 and 40 mg·cm^{-2}. The mass of ZnS(Ag) corresponding to this thickness was adopted as the optimum for cuvets of different sizes. For routine measurements with the 25 mm-diameter cuvet, the optimum mass of scintillation powder is 150 mg. The use of the small cuvet for routine samples has made it possible to decrease both the background of the radiometer and the dimensions of each individual module which is an important consideration when multiple modules are built into one unit.

The method, described above, has been successfully used at the laboratory for determination of alpha-activity in excreta samples and in tissue samples taken at autopsy. To check the accuracy of the radiometer, aliquots of acid-dissolved samples, from which americium had been radiochemically separated, were analyzed by the radiometer and also by alpha-spectrometer after electrodeposition on planchets. The results of the two measurements are shown in Table 2. The data in Table 2 indicate that the total alpha-activity values determined by both methods of analysis were in very close agreement. Results from only two of 14 samples differed by more than 25% and most compared measurements were within 10% of each other. The results reflect the effectiveness of the alpha radiometer if the nuclide composition of the samples is adequately known.

Table 2. A comparison of alpha-spectrometric results with those from alpha radiometric analysis of aliquots of the same samples

Sample number	Tissue	Tissue weight[a]	Radiometry Total plutonium, dpm	Spectrometry Isotopic activity, dpm $^{239+240}Pu$	Spectrometry Isotopic activity, dpm ^{238}Pu	Ratio of Spectroscopy/ Radiometry
1	Liver	180.3	12.80 ± 1.16[b]	14.55 ± 0.29	2.30 ± 0.11	1.32
2	Liver	433.9	5.22 ± 0.23	4.79 ± 0.19	0.12 ± 0.03	0.94
3	Lung	661.3	9.64 ± 1.01	8.91 ± 0.25	0.22 ± 0.04	0.95
4	Lung	447.5	5.82 ± 0.26	3.48 ± 0.16	0.11 ± 0.03	0.62
5	Lung	178.2	2.68 ± 0.17	3.10 ± 0.15	0.12 ± 0.03	1.20
6	Heart	141.0	8.19 ± 0.66	7.79 ± 0.26	0.05 ± 0.02	0.96
7	Cranium	9.7	13.60 ± 1.18	13.15 ± 0.32	0.07 ± 0.02	0.97
8	Cranium	14.1	3.28 ± 0.21	3.16 ± 0.16	0.10 ± 0.03	0.99
9	Ribs	0.3	9.76 ± 1.01	8.69 ± 0.25	0.26 ± 0.04	0.92
10	Vertebra	4.9	9.54 ± 1.10	8.03 ± 0.26	1.51 ± 0.11	1.00
11	Vertebra	0.2	10.77 ± 1.09	9.90 ± 0.24	0.07 ± 0.02	0.93
12	Femur	1.0	11.56 ± 1.10	11.82 ± 0.29	0.30 ± 0.05	1.05
13	Femur	8.6	7.40 ± 0.64	7.66 ± 0.24	0.09 ± 0.03	1.05
14	Patella	10.4	3.33 ± 0.26	3.24 ± 0.15	0.16 ± 0.03	1.02
Mean ± SE:						0.99±0.04

[a] Wet weights for soft tissues and ashed weights for bones.
[b] Uncertainty estimates are one standard deviation measurement uncertainty.

Conclusions

The scintillation method, described above, has been used to analyze the actinide contents in the excreta of more than 7000 employees of the Mayak plutonium production facility and in several tens of thousands of tissue samples collected at autopsy of persons of the facility and the members of the general population. The method is efficient, easy to use and is relatively inexpensive. The information gained with this method was of great importance to the Mayak dosimetry control system and was used to monitor population exposures to the actinide elements.

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This work was conducted under the auspices of the Joint Coordinating Committee for Radiation Effects Research (JCCRER) with funding provided by the U.S. Department of Energy Office of International Health Programs.

References

1. Russian Federation State Standard Number 397/96. Radiometer of Alpha Radiation RIA-05, General State Center for Measurement Standards, D. Mendeleev NPO VNIIM, Saint Petersburg, Russia, 1996, (in Russian.)
2. Russian Federation State Standard Number 39-2/93. Plutonium: Method for Anion-exchange Estimation of Low-level Alpha-activity in Autopsy Specimens, General State Center for Measurement Standards, D. Mendeleev NPO VNIIM, Saint Petersburg, Russia, 1993, (in Russian.)
3. K. G. SUSLOVA, R. E. PILIPY, V. F. KHOKHRYAKOV, S. A. ROMANOV, R. L. KATHREN, Radiat. Protect. Dosim., 67 (1996) 13.
4. B. BOECKER, R. HALL, K. INN, J. LAWRENCE, P. ZIEMER, G. EISELE, B. WACHHOLZ, W. BURR, Jr., Health Phys., 60 (Suppl. 1) (1991) 45.

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Project 2.1
Metabolism and Dosimetry of Plutonium Industrial Compounds

for the period

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Executive Summary

The long-term collaborative research project between the United States Transuranium and Uranium Registries (USTUR), operated by Washington State University, and the Dosimetry Registry of the Mayak Industrial Association (DRMIA), operated by Branch No. 1 of the Federal Research Center, Institute of Biophysics (FIB-1) officially began on 1 February 1997. The first semi-annual progress report by the project was submitted in October, 1997. This report is a summary of progress for the period between 1 October 1997 and 10 March 1998.

Intercomparison of the radiochemical analytical methods used by each laboratory for autopsy tissue analyses, both past and present, remains a high-priority task of this project. Comparisons of the actinide detection systems used by each laboratory by an exchange of samples were discussed in the previous progress report. The USTUR has used surface-barrier detectors for alpha spectrometry for many years; the DRMIA uses two types of detectors, the alpha radiometer which works on a ZnS(Ag) scintillation principle and the alpha spectrometer which is based on an ionization chamber design. In the first comparison, the results from measurement of plutonium in samples were generally in good agreement among the three instruments; however, some difficulty was experienced with measurement of americium with the DRMIA alpha spectrometer.

The second round of comparisons was by an exchange of dehydrated acid-dissolved tissue solutions. This exchange was designed to compare radiochemical separation methods as well as the actinide detection instrumentation and the results of these comparisons are reported in this report. There were occasional statistically significant differences between pairs of measurements made by the two laboratories; however, there was no consistent systematic bias between laboratories or methods. These results indicate the potential of combining USTUR and DRMIA tissue actinide concentration data for the study of actinide metabolism in occupationally-exposed workers of both countries. The format for a database to contain such data from both Registries, for use in this collaborative project has been determined and the data entry process is underway.

The DRMIA has modified their wet-chemical analytical procedures to include reagents and methods used by the USTUR radiochemistry laboratories. They have recently purchased an EG&G OCTETE alpha spectrometry system. Two DRMIA scientists have visited the USTUR laboratories to gain experience with USTUR actinide separation and analytical methods, including the setup, operation, and maintenance of the hardware and software associated with the OCTETE system. These changes are expected to improve the uniformity of methods used by the two laboratories for analyses of samples collected in the future.

The FIB-1 has entered into an agreement with the Mayak Production Association to continue their investigation of the "transportability", or in-vitro solubility, of workplace aerosols containing alpha activity. During this reporting period, they performed their "dialysis" technique on workplace aerosols collected from three sites within the Mayak facility. The results of their tests led them to conclude that the personnel in the workplaces sampled were exposed to relatively soluble forms of plutonium-containing aerosols with dialysis half-times of 136 and 415 days. The DRMIA is seeking to obtain additional cascade impactors with which to incorporate particle size analyses with the dialysis method.

During this reporting period, the FIB-1 took initial steps toward improving their in vivo counting facility. A reasonably modern in vivo detection system at the U. S. Rocky Flats Plant was no longer in use and was to be excessed. The system is complete with a specially shielded room, high-purity germanium detectors, and associated electronics as well as phoswich detectors to be installed as backup detectors. David Hickman of Lawrence Livermore National Laboratory is responsible to oversee the refurbishment of the equipment and installation at the FIB-1 site. Calibration of the system, a task of this project, will began when the equipment is operational, expected to be in July or August, 1998. Existing in vivo detection equipment will be calibrated simultaneously for verification of in vivo measurement data already collected.

A U. S. National Council on Radiation Protection and Measurements (NCRP) Committee on Radionuclide Dosimetry Models for Wounds requested that USTUR and DRMIA personnel translate, into English, two Russian documents dealing with intake of actinides through skin injuries. This was initiated during the visit of DRMIA scientists to USTUR facilities in 1997 and the reports will be prepared for submission for publication, in English, in the scientific literature.

Introduction

The long-term collaborative research project between the United States Transuranium and Uranium Registries (USTUR), operated by Washington State University, and the Dosimetry Registry of the Mayak Industrial Association (DRMIA), operated by Branch No. 1 of the Russian Institute of Biophysics (FIB-1), officially began on 1 February 1997. It was preceded by a one-year feasibility study during which the scopes, operations, methods, and previously obtained results of the two Registries were compared (Suslova et al. 1996).

The main purpose of this project is the detailed study of the metabolism of plutonium and americium in the human body and the development of biokinetic models to describe that metabolism. This will be achieved by analysis and interpretation of the databases of both Registries which contain actinide concentrations in tissues and organs that were collected at autopsy of personnel from Russian and American nuclear facilities.

Tasks to be performed were described in the proposal which was approved for funding and they were scheduled for initiation and completion at various times during the three-year period (Figure 1). The tasks included:

Task A--To compare radiochemical analytical methods for actinides currently in use by both Registries with a series of performance evaluations;

Task B--To establish a common database format that can be used by both Registries for completion of tasks F, G, and H, listed below;

Task C-- To coordinate tissue sampling methods used by the two Registries including specific tissues and organs sampled, mass of the sample, and specific structures to be included in a sample, thus improving and making more exact data comparisons;

Task D--To coordinate radiochemical analytical methods used by both Registries to determine actinide contents of tissue samples, including ashing methods, actinide separation techniques, spectroscopy methods, and data recording;

Task E--To characterize workplace aerosols at the Mayak facility and American facilities

Task F--To establish transfer coefficients, based on the systemic:lung:lymph node activity ratios measured by both Registries, that describe the transfer of various plutonium and americium compounds from the lungs to the blood and compare the coefficients with those predicted by the new ICRP-66 (1994) models for the purpose of testing the model directly with human, long-term exposure data;

Task G--To determine the relationships between actinide concentrations of organs of the body and between individual organs and total body burdens in healthy individuals as well as in those with health impairment, specifically those with liver diseases;

Task H--To test the relationships between actinide contents of the lungs and body organs at autopsy and the long-term, temporal pattern of urinary excretion predicted by the current ICRP metabolic models for plutonium and americium (ICRP-67 1994) and to compare actinide metabolism and long-term urinary excretion of the actinides in healthy individuals with that in health-impaired individuals, specifically in those with liver diseases;

Task I--To improve the in vivo counting capabilities of the DRMIA and perform calibrations and intercomparisons with other, similar facilities so that it is a more useful tool for characterizing the intake and retention of actinide elements; and;

Task J--To translate previously classified relevant Russian documents into English for submission to peer-reviewed journals or for publication as topical reports, as appropriate.

Progress

Task A

Task A is a high-priority task which was necessary as a quality assurance measure and is needed to verify the validity of use of the data of both Registries together. It was planned to be accomplished in 3 steps:

1. Intercomparison of instrumental methods and equipment for plutonium and americium measurements.

2. Intercomparison of radiochemical separation as well as measurement methods, and,

3. Analyses of Standard Reference Materials (SRM) prepared by the U. S. National Institute of Standards and Technology (NIST).

The differences between the radiochemical analytical methods and detection instruments currently in use by both Registries were described in an earlier report (Suslova et al. 1996) so they are only briefly described here.

For routine measurement of alpha activity in biological samples, the DRMIA primarily used the alpha radiometer which is based on the ZnS(Ag) scintillation principal. They used VP 1-AP anion exchange resin for separation of the actinides and extracted americium with diethyl-hexyl-phosphoric acid (HDEHP) and the actinides were co-precipitated from solution with bismuth phosphate. The precipitate was mixed with the ZnS(Ag) scintillation powder for the alpha radiometer (Khokhryakov et al. 1996a).

The DRMIA also used an alpha spectrometer (SEAM), based on an ion chamber design, for samples containing low levels of the actinides and for samples with unknown isotopic composition. Radiochemical separation was initially the same as for the alpha radiometer (above); however, the DRMIA has recently switched to Bio-Rad anion exchange resins (AG 1-X4 dnd AG MP-1) and now extracts americium with dibutyl-N,N-diethylcarbamoyl phosphonate (DDCP). The actinides are electrodeposited from solution onto 35 mm-diameter stainless steel disks for spectrometry.

The USTUR has performed alpha spectrometry with silicon surface-barrier detectors for a number of years and currently uses an EG&G OCTETE system. The use the AG 1-X4 and AG MP-1 anion exchange resins and extract americium with DDCP. The actinides are electrodeposited onto 16 mm-diameter stainless steel disks for spectrometry.

The results of the first laboratory intercomparison were reported in the previous progress report (Khokhryakov et al. 1997). As part of that comparison, the DRMIA provided polystyrene cuvets containing $BiPO_4$+Pu+ZnS(Ag) precipitate that had been previously counted with the DRMIA alpha radiometer. The USTUR chemically separated out the plutonium and counted it with the USTUR alpha spectrometer. The results of these analyses are included in Table A-1 of this report and, although the total plutonium detected in one sample (165) was statistically different between the two laboratories ($P<0.05$), the overall interlaboratory difference was not statistically significant at the 95% confidence level. Measurements made with the alpha spectrometers of the two laboratories on electrodepositions upon stainless steel disks provided by the USTUR were, likewise, not statistically different at the 95% confidence level. However, some problems were encountered with the detection of ^{241}Am by the DRMIA alpha spectrometer which resulted in greater differences between measurements of that actinide from the two laboratories than for plutonium.

The second interlaboratory comparison included the radiochemical analysis of ten samples prepared by each laboratory. The samples consisted of aliquots of dehydrated acid-dissolved tissues contining between 0 and 1 Bq of americium and/or plutonium. The purpose of this sample exchange was to compare the results of radiochemical extraction methods and to measure the isotopic composition of the samples. Most of the samples provided to the USTUR by the DRMIA had been previously measured with the alpha radiometer as well as the DRMIA spectrometer by the methods briefly described above. The results of those analyses for plutonium and amercium are compared in Tables A-2 and A-3, respectively. There were no overall statistically significant differences ($P<0.05$)

between the results obtained by DRMIA alpha radiometry, DRMIA alpha spectrometry, and USTUR alpha spectrometry.

^{238}Pu, $^{239+240}Pu$, and ^{241}Am contents in DRMIA samples analyzed by the USTUR are shown in Tables A-4, A-5, and A-6 and the results of DRMIA analyses of samples provided by the USTUR are shown in Tables A-7, A-8, and A-9. Captions on those tables explain the methods that were compared and the conclusions drawn from statistical analyses are included below each table. Figures A-1 through A-9 are graphic representations of the data in the tables.

Task B

Both Registries have computerized databases of medical and exposure histories, bioassay data, and autopsy tissue radioanalytical data for occupationally-exposed workers from plutonium production facilities in their respective countries. Although the databases of the two Registries utilize different software, the DRMIA database with FOX-PRO and the USTUR with PARADOX, both are capable of importing and exporting files from other databases and by using text files. The purpose of Task B is to create a single database that will be available to both Registries for studies of the biokinetics of plutonium and americium (Tasks F, G, and H). Specific data to be included in this database were determined during the previous reporting period and were described in the last progress report (Khokhryakov et al. 1997).

Preliminary investigations by the DRMIA indicate that the state of health of an individual may influence the metabolism of actinides, and therefore affect such important parameters as the urinary excretion rate and the actinide distribution in tissues and organs. This is particularly true when the subject suffers from liver disease such as fatty degeneration, primary or metastatic liver cancer, and cirrhoses. Both Registries have identified these types of cases in their respective databases to further investigate this phenomenon and the shared database will thus contain a "health status" record that indicates such disease states. This will permit comparison of cases with liver disease to those without known liver disease, and to subjects who died as a result of accidents or from such causes as cardiovascular diseases.

Task C

This task was considered concluded during the previous reporting period (Khokhryakov et al. 1997).

Task D

Intercomparability and consistancy of radiochemical analytical methods used by both Registries is a high-priority task. A major goal of this task is to improve existing analytical methods methods (anion exchange and extraction) and detection methods (alpha spectrometry) in both laboratories. This task is of particular importance to the DRMIA and consists of three steps:

1. Modification of radiochemical analytical procedures for separation of plutonium and americium from biosamples by application of effective reagents currently in use by the USTUR such as the Bio-rad® resins and the DDCP extractant.

2. Development of alpha spectrometric capability by acquisition and installation of new equipment, an EG&G Ortec OCTETE® system and electroplating apparatus for use with stainless steel disks suitable for use with that system.

3. Acquisition of TRU Spec® materials, currently under evaluation by the USTUR, for rapid, single-step separations of actinides from biosamples.

The DRMIA has acquired the new Bio-rad resin (AG MP-1) and the DDCP americium extractant and is using them in conjunction with their alpha spectrometry system. To confirm and ensure the quality of previously obtained data and the reliability of the new resins and reagents, the DRMIA performed a series of comparisons between their old and new methods. The first comparison of the original alpha radiometry measurements with the DRMIA alpha spectrometry measurements using the Bio-rad resins was described in the previous progress report (Khokhryakov et al. 1997). Based on nine samples, the mean ratio of spectrometry results to radiometry results was 1.02 ± 0.05 (mean $\pm$ standard error).

The second comparison was made during this reporting period with 18 samples, for both plutonium and americium. The results are shown in Tables D-1 and D-2 and the results of a further comparison with USTUR alpha spectrometry, with 10 of those samples are shown in Tables A-2 and A-3. Statistical analysis of the data indicate no significant differences among any of the three methods ($P<0.05$).

The DRMIA has recently purchased an EG&G Ortec OCTETE alpha spectrometry system which will be installed during the second quarter of 1998. In December, 1997, two DRMIA scientists, a computer specialist responsible for installing the OCTETE spectrometry system and a chemist responsible for the radiochemical separation of actinides from tissue and urine bioassay samples visited the USTUR radiochemistry laboratories. A primary goal of this visit was to familiarize these DRMIA staff members with the alpha spectrometry hardware and software in order to expedite the implementation of the new equipment and to gain experience with the new USTUR electrodeposition and americium separation procedures. They were also briefed on the

hardware setup and maintenance and introduced to the software and gained experience in the initial setup of the software, energy and efficiency calibrations, background determinations, QA/QC and ANSI N13.30, and sample analysis as well as the use of the EXCEL® spreadsheet for data analysis.

During the visit, the DRMIA chemist prepared two mixed isotope sources by electrodeposition which were counted in the USTUR alpha spectrometry system. These sources were taken to the DRMIA laboratory to use in the initial calibration of their new spectrometer pending the purchase of a NIST Standard Reference Material point source and preparation of their own secondary calibration sources.

Task E

FIB-1 and the Radiation Protection Service Department of the Mayak Production Association have formed a joint program to study the physico-chemical properties of workplace aerosols containing plutonium. Measurements of in-vitro solubility of workplace aerosols were begun in early 1998 with the analysis of three air samples collected on filter paper. The method of analysis, using a dialysis system with Ringer's physiological solution was described in an earlier report (Khokhryakov et al. 1998b).

Dialysis kinetics of plutonium-containing workplace aerosols can be described by an equation with two exponentially decreasing components:

$Q = Q_0 [a_1 \exp(-\lambda_1 t) + a_2 \exp(\lambda_2 t)]$, where:

Q_0 is the initial content of plutonium alpha activity on the sample filter,

a_1 is the percent of alpha activity dialysing with the constant λ_1,

λ_1 is the constant corresponding to the dissolution rate of the rapidly diffusing, soluble fraction into the external solution.

a_2 is the percent of alpha activity dialysing with the constant λ_2, and

λ_2 is the constant corresponding to the dissolution rate of the slow dissolution rate of large particles breaking down.

Transportability $(S) = a_1 + a_2\lambda_2/\lambda_1$, expressed as percent.

Dialysis of the samples in Ringer's solution was continued for two weeks recording the cumulative percent of plutonium dialyzed from the filter sample each day. Analysis of these dialysis plots by the method of least squares resulted in the following parameters:

For more soluble aerosols: $a_1 = 3.82\%$, $\lambda_1 = 5.515\ day^{-1}$, $a_2 = 96.18\%$, and $\lambda_2 = 0.00511\ day^{-1}$.

For less soluble aerosols: $a_1 = 0.156\%$, $\lambda_1 = 17.23\ day^{-1}$, $a_2 = 99.844\%$, and $\lambda_2 = 0.00167\ day^{-1}$.

The dissolution half-time for the slower component of the more soluble aerosol was 136 days and, for the less soluble aerosols, it was 415 days. This indicates that the personnel in the workplace investigated were exposed to relatively soluble plutonium aerosols.

This same technique will ultimately be performed in conjunction with partical size analysis; however, this has been postponed due to a lack of equipment. The most suitable apparatus for such a purpose is the Anderson High-Volume Cascade Impactor with five stages, Model 65-000. The FIB-1 has one such instrument which has been used for monitoring ambient air in the Ozyorsk community. To avoid the possibility of contamination, this instrument should not be used for workplace sampling and the possibility of obtaining more such instruments is under investigation.

Task I

The plan for this task was to modernize the detectors used for in vivo counting by the FIB-1 by replacement of the existing NaI(Tl) detectors with more sensitive equipment. Originally, phoswich detectors were proposed as these do not require cryogenic operation and the constant availability of liquid nitrogen was not certain. The objective is to increase the sensitivity of the FIB-1 in vivo counter so the facility could be better used to quantitate low-level actinide intakes in the Mayak personnel.

During this reporting period, it was learned that the Rocky Flats Plant in Denver, Colorado had a reasonably modern in vivo counting facility which was no longer used and was to be excessed. The Rocky Flats facility consists of a specially designed, low-background, shielded room with a set of high-purity germanium detectors and associated electronics. Under the auspices of the DOE Office of International Health Studies, David Hickman of Lawrence Livermore National Laboratory will oversee refurbishment of this equipment and its physical transfer to FIB-1. A Canberra ABACOS computer-based system will also be procured and provided for use with the shield and detectors. Rocky Flats also has a set of phoswich detectors which will be installed with the system as backup detectors.

To accomodate the new equipment an addition onto the existing FIB-1 in vivo counting facility will be necessary. The preparation of cost estimates is currently underway and it is anticipated that construction will be completed in July or August, 1998. At that time, installation and initial calibration will began. Ultimately, calibration will be accomplished

with the use of a phantom library maintained by Pacific Northwest National Laboratory (PNNL) at Richland, Washington. The library includes the USTUR-owned ^{241}Am phantoms which are on long-term loan to PNNL to facilitate their loan and use by other laboratories. The existing FIB-1 in vivo counting facility will also be calibrated for verification of data already collected.

Task J

Three scientific reports, stemming from this collaborative research project, have been accepted for publication and are currently in press in the peer-reviewed scientific literature. They are included in the list of references, below (Filipy et al. 1998; Khokhryakov et al. 1998a; Khokhryakov et al. 1998b) and the abstracts are included with this report. The latter two of the reports were Russian documents translated to English in partial fulfillment of this task.

Two other Russian documents have also been translated to English and the abstracts are included with this report. These documents were selected by the U. S. National Council on Radiation Protection and Measurements (NCRP) and were considered to have direct applicability to the work of NCRP Committee 57-17, Radionuclide Dosimetry Model for Wounds. The authors and translated titles of the reports are:

The risk of intake of plutonium and americium-241 through skin injuries by radiochemical facility personnel. Khokhryakov, V. F.; Kudryavtseva, T. I; Shevkunov, V. A.

Injuries and Skin Burns with Alpha Activity Contamination among Mayak Workers Bazhin, A. G.; Khokhryakov, V. F.; Shevkunov, V. A.

References

Filipy, R. E.; Khokhryakov, V. F.; Suslova, K. G.; Romanov, S. A.; Stuit, D. B.; Aladova, E. E.; Kathren, R. L. Analysis for Actinides in Tissue Samples from Plutonium Workers of Two Countries. Journal of Radioanalytical and Nuclear Chemistry. 1998. (in press)

International Commission on Radiological Protection. Human Respiratory Tract Model for Radiological Protection. Oxford: Pergamon Press; ICRP Publication 66; Ann. ICRP 24(1-3):1-482; 1994.

International Commission on Radiological Protection. Age-dependent doses to members of the public from intake of radionuclides, Part 2. Oxford: Pergamon Press; ICRP Publication 67; Ann. ICRP 23(3/4):1-167; 1994.

Khokhryakov, V. F.; Suslova, K. G.; Aladova, E. E.; Orlova, I. A.; Chernikov V. I.; Filipy, R. E.; Stuit, D. B.; Glover, S. E.; Filby, R. H.; Kathren, R. L. Progress report number 3, Project 2.1-Metabolism and Dosimetry of Plutonium Industrial Compounds. 1 February - 30 September 1997. USTUR-0089-97; 1997.

Khokhryakov, V. F.; Suslova, K. G.; Tseveloyova, I. A.; Aladova, E. E.; Filipy, R. E. Classification of Alpha-active Workplace Aerosols Based on Coefficient of Transportability, Measured by the Dialysis Method. Journal of Radioanalytical and Nuclear Chemistry. 1998b. (in Press).

Khokhryakov, V. F.; Kudravtseva, T. I.; Chernikov, V. I.; Orlova, I. A.; Filipy, R. E. A Scintillation Method for Determination of Actinide-Alpha Activities in Samples. Journal of Radioanalytical and Nuclear Chemistry. 1998a. (in press).

Suslova, K. G.; Filipy, R. E.; Khokhyrakov, V. F.; Romanov, S. A.; Kathren, R. L. Comparison of the Dosimetry Registry of the Mayak Industrial Association and the United States Transuranium and Uranium Registries: A preliminary report. Radiat. Protect. Dosimetry 67:13-22; 1996.

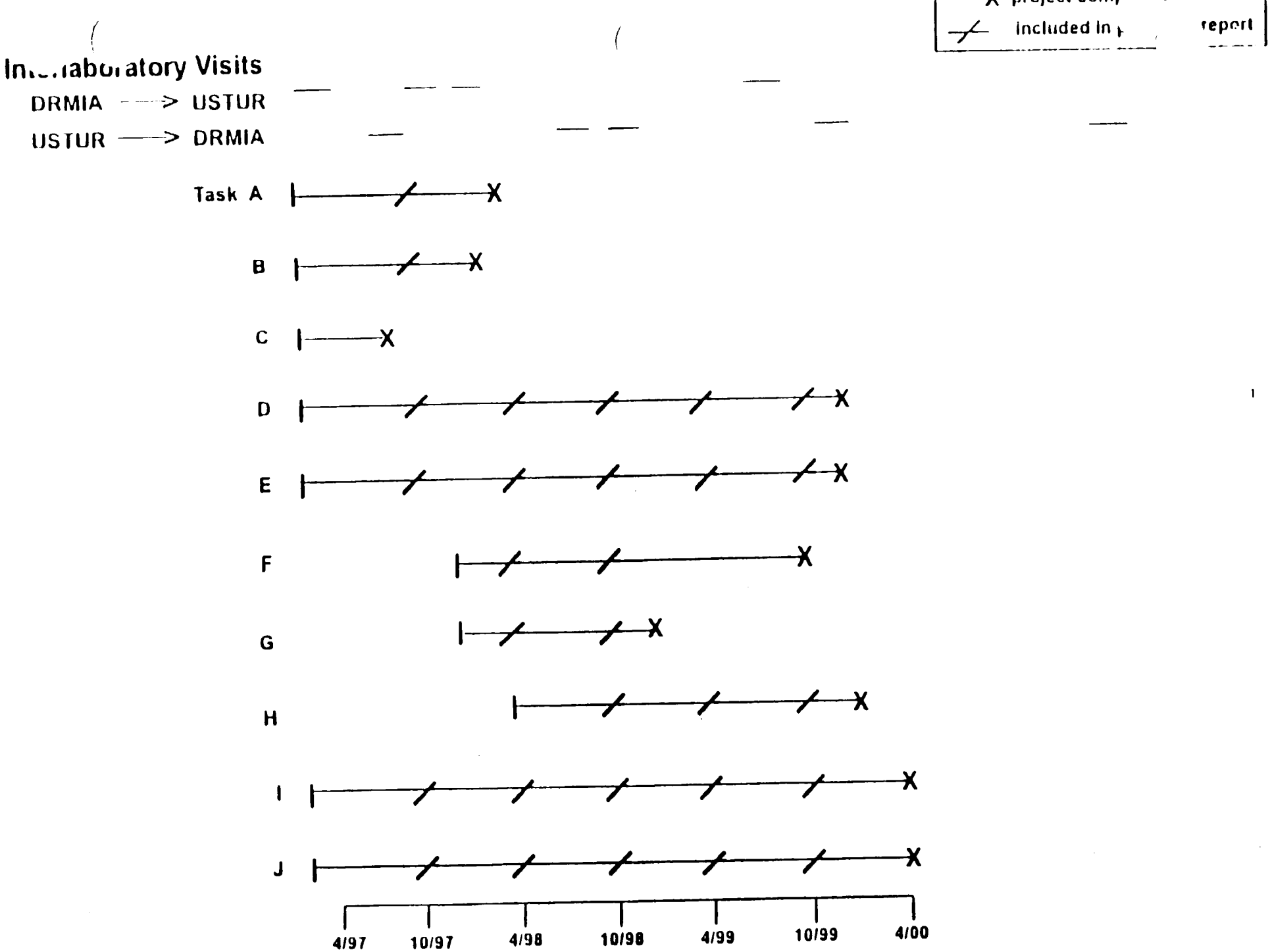

Figure 1. Schedule of Proposed Tasks